Using movement sonification to alter body perception and promote physical activity in physically inactive people

by

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To my mom, she will always be my friend, my support, my everything.

To my boyfriend who was always by my side and make me happier.

Eye of the tiger;

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PUBLISHED AND SUBMITTED CONTENT

Some of the results presented in this thesis has been published in conferences and journals as part of the requirements of the PhD program in Computer Science and Technology. These articles realized by the author have been partially included as part of this thesis:

1. Journals
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OTHER RESEARCH MERITS

1. Articles
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   - (Submitted) **Body weight distortions in an auditory-driven body illusion in subclinical and clinical eating disorders**" Authors: Ana Tajadura-Jiménez, Laura Crucianelli, Rebecca Zheng, Chloe Cheng, *Judith Ley-Flores*, Mercedes Bordá-Más, Nadia Bianchi-Berthouze, and Aikaterini Fotopoulou. URL: https://www.nature.com/srep/guestedited#the-bodily-self
   - **Interactive sonification to assist children with autism during motor therapeutic interventions** (2021). Authors: Franceli L. Cibrian, *Judith Ley-Flores*, Joseph W. Newbold, Aneesha Singh, Nadia Bianchi-Berthouze, Monica Tentori. Personal Ubiquitous Computing 25, 391–410. Impactor factor: 3.006 (**Q2**), DOI: https://doi.org/10.1007/s00779-020-01479-z.
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ABSTRACT

Worldwide, one out of four adults are not physically active enough. Supporting people to be physically active through technology remains thus an important challenge in the field of Human-Computer Interaction (HCI). Some technologies have tried to tackle this challenge of increasing physical activity (PA) by using sensing devices for monitoring the amount and quality of PA and providing motivational feedback on it. However, such technologies provide very limited support to physically inactive users: while users are aware of their physical inactivity level, they are frequently incapable of acting on these problems by themselves. Among the reasons for it are negative perceptions about one's body (e.g., feelings of body tiredness or weakness in self-esteem) which may act as psychological barriers to PA.

This research project aims to address this limitation by employing an approach that, through movement sonification (i.e., real-time auditory feedback on body movement), exploits bottom-up multisensory mechanisms related to BPs to ultimately support PA. This thesis presents the design, development, and evaluation of SoniShoes and SoniBand, two wearable technological devices with a gesture-sound palette that allows for a range of body movement sonifications aimed to alter BPs. These prototypes aim at changing BPs, and in turn emotional state and movement behavior, to address psychological barriers related to the perception of one's body, and ultimately impact positively on people's adherence to PA.

First, this work proposes to organize knowledge through a taxonomy of the barriers to PA related to body perception (BP), which follows a process of four steps to inform the design of the movement-sound palette: (1) Identification, (2) Extraction and clustering of attributes, (3) Definition of instructions or considerations, and (4) Strategies. The first two steps allowed the identification and grouping of barriers to PA that are related to BPs, with inputs from a literature review, a survey, and a focus group with HCI experts. The third and fourth steps allowed defining the body features and dimensions to act upon, to finally propose movement sonification strategies that have the potential to tackle the barriers.

Second, several movement-sound mappings, based on metaphors, are presented. Movements were selected from exercises included in guidelines for becoming more physically active (e.g., walking). The mappings of these movements into sounds were

implemented in SoniShoes and SoniBand prototypes. They were evaluated through an iterative process, starting with an exploratory study that tested for the first time the potential of the proposed mappings to change BPs. In this first study, participants were asked to think aloud about their experiences using the first prototype of SoniShoes (from MagicShoes project), by describing their body sensations and sound characteristics during the exercise. Results suggested the potential of movement sonification to alter BP through movement sonification and informed the design of the subsequent studies and prototypes. This exploratory study was followed by quantitative and qualitative studies aimed to understand how to design movement sonifications and wearable devices integrating them to facilitate PA by tackling barriers related to BP. The quantitative studies were controlled laboratory studies, in which different versions of SoniShoes and SoniBand prototypes were evaluated, and which results led to further iterations of the prototypes. The results of these quantitative evaluations revealed movement-sound mappings that can lead to changes in feelings about the body (e.g., feeling lighter or less tired), feelings about the movement (e.g., having more movement control over the movement), and emotional feelings (e.g., having more comfort, motivation to complete the exercise, or feeling happier) during PA. Results also showed effects of sound on movement behavior, such as effects in movement deceleration/acceleration and stance time, and proprioceptive awareness. Furthermore, two qualitative studies were carried out, which involved using the SoniBand prototype for several days and in two different contexts of use, laboratory and home. The aim of these studies was two-fold. First, elucidating the effects that particular metaphorical sonifications' qualities and characteristics have on people's perception of their own body and their PA. Second, understanding how the observed effects may be specific to physically inactive (vs. active) populations. The results revealed specific connections between properties of the movement sonifications (e.g., gradual or frequency changes) on the one hand, and particular body feelings (e.g., feeling strong) and aspects of PA (e.g., repetitions) on the other hand, but effects seem to vary according to the PA-level of the populations.

Finally, the findings, contributions, and principles for the design of movement sonifications and wearable technology to promote PA through acting upon BP are discussed, finishing by considering implications for potential interventions and applications supporting PA, as well as opportunities opened for future research.

RESUMEN

En todo el mundo, uno de cada cuatro adultos no es lo suficientemente activo físicamente. Por ello, ayudar a las personas a ser físicamente activas a través de la tecnología sigue siendo un reto importante en el campo de "Human-Computer Interaction" (HCI). Algunas tecnologías han tratado de abordar el reto de aumentar la actividad física (PA) mediante el uso de dispositivos de detección para controlar la cantidad y la calidad de la PA y proporcionar retroalimentación motivacional al respecto. Sin embargo, estas tecnologías proporcionan una ayuda muy limitada a los usuarios físicamente inactivos: aunque los usuarios son conscientes de su nivel de inactividad física, a menudo son incapaces de actuar por sí mismos sobre estos problemas. Entre las razones están las percepciones negativas sobre el propio cuerpo (por ejemplo, la sensación de cansancio corporal o el no sentirse capaces) que pueden actuar como barreras psicológicas para la PA.

Este proyecto de investigación pretende abordar esta limitación empleando un enfoque que, a través de la sonificación del movimiento (es decir, la retroalimentación auditiva en tiempo real sobre el movimiento del cuerpo), explota los mecanismos "bottom-up" multisensoriales relacionados con las percepciones del cuerpo (BPs) para apoyar la PA. Esta tesis presenta el diseño, el desarrollo y la evaluación de "SoniShoes" y "SoniBand", dos dispositivos tecnológicos vestibles con una paleta de gestos y sonidos que permiten una serie de sonificaciones del movimiento corporal destinadas a modificar las BPs. Estos prototipos tienen como objetivo cambiar las BPs, y a su vez el estado emocional y el comportamiento de movimiento, para abordar las barreras psicológicas relacionadas con la BP, y en última instancia impactar positivamente en la adherencia de las personas a la PA.

En primer lugar, este trabajo propone organizar el conocimiento a través de una taxonomía de las barreras a la PA relacionadas con la BP, que sigue un proceso de cuatro pasos para informar el diseño de la paleta de movimiento-sonido: (1) Identificación, (2) Extracción y agrupación de atributos, (3) Definición de instrucciones o consideraciones, y (4) Estrategias. Los dos primeros pasos permitieron identificar y agrupar las barreras a la PA relacionadas con los BP, con aportaciones de una revisión bibliográfica, una encuesta y un grupo de discusión con expertos en HCI. El tercero y cuarto paso permitió definir las características y dimensiones corporales sobre las que actuar, para finalmente

proponer estrategias de sonificación del movimiento que tienen el potencial de abordar las barreras.

En segundo lugar, se presentan varios mapeos de movimiento-sonido, basados en metáforas. Los movimientos se seleccionaron a partir de ejercicios incluidos en las guías para ser más activos físicamente (por ejemplo, caminar). Los mapeos de estos movimientos en sonidos se implementaron en los prototipos "SoniShoes" y "SoniBand". Se evaluaron a través de un proceso iterativo, comenzando con un estudio exploratorio que probó por primera vez el potencial de los mapeos propuestos para cambiar los BP. En este primer estudio, se pidió a los participantes que pensaran en voz alta sobre sus experiencias utilizando el primer prototipo de "SoniShoes" (llamado "MagicShoes"), describiendo sus sensaciones corporales y las características del sonido durante el ejercicio. Los resultados mostraron el potencial de la sonificación del movimiento para alterar la BP a través de la sonificación del movimiento e informaron el diseño de los estudios y prototipos posteriores. A este estudio exploratorio le siguieron estudios cuantitativos y cualitativos destinados a comprender cómo diseñar sonificaciones del movimiento y dispositivos vestibles que las integren para facilitar la PA abordando las barreras relacionadas con la BP. Los estudios cuantitativos fueron estudios de laboratorio controlados, en los que se evaluaron diferentes versiones de los prototipos "SoniShoes" y "SoniBand", y cuyos resultados condujeron a nuevas iteraciones de los prototipos. Los resultados de estas evaluaciones cuantitativas mostraron que existen mapeos de movimiento-sonido que pueden provocar cambios en las sensaciones sobre el cuerpo (por ejemplo, sentirse más ligero o menos cansado), en las sensaciones sobre el movimiento (por ejemplo, tener más control sobre el movimiento) y en las sensaciones emocionales (por ejemplo, tener más comodidad, motivación para completar el ejercicio o sentirse más feliz) durante la PA. Los resultados también mostraron los efectos del sonido en el comportamiento del movimiento, como los efectos en la desaceleración/aceleración del movimiento y el tiempo de postura, y la conciencia propioceptiva. Además, se llevaron a cabo dos estudios cualitativos, en los que se utilizó el prototipo "SoniBand" durante varios días y en dos contextos de uso diferentes, el laboratorio y el hogar. El objetivo de estos estudios era doble. En primer lugar, dilucidar los efectos que determinadas cualidades y características de las sonificaciones con metáforas tienen en la percepción que las personas tienen de su propio cuerpo y de su PA. En segundo lugar, comprender cómo los efectos observados pueden ser específicos de las poblaciones físicamente inactivas (vs. las activas). Los resultados revelaron conexiones específicas entre las propiedades de las sonificaciones de movimiento (por ejemplo, los cambios graduales o de frecuencia) por un lado, y las sensaciones corporales particulares (por ejemplo, sentirse fuerte) y los aspectos de la PA (por ejemplo, las repeticiones) por otro lado, pero los efectos parecen variar según el nivel de PA de las poblaciones.

Por último, se discuten los hallazgos, las contribuciones y las guías de diseño de sonificación de movimiento y tecnología vestible para promover la PA a través de la actuación sobre la BP, para finalmente considerar las implicaciones para las posibles intervenciones y aplicaciones de apoyo a la PA, así como las oportunidades abiertas para futuras investigaciones.

LIST OF ABBREVIATIONS

Abbreviation	Term
PA	Physical Activity
BP	Body Perceptions
HCI	Human-Computer Interaction
WHO	World Health Organization
RQ	Research Question
SO	Specific Objective
BQPA	Barriers Questionnaire for Physical Activity
IFiS	International Fitness Scale
IPAQ	International Physical Activity Questionnaire
IPAQ-SF	International Physical Activity Questionnaire Short Form
ACM	Association For Computing Machinery
HBM	Health Belief Model
CP	Chronic Pain
FSR	Force-Sensitive Resistors
UCL	University College London
IMU	Inertial Motion Unit
OSC	Open Sound Control
MET	Metabolic Equivalent of Task
ACII	Affective Computing and Intelligent Interaction
SAM	Self-Assessment Manikin
EDA	Electrodermal Activity
BVP	Blood Volume Pulse
SPSS	Statistical Package for The Social Sciences
ANOVA	Analysis Of Variance
LSD	Least Significant Difference
ART	Aligned Rank Transform
AP	Active People
IP	Inactive People
NHS	National Health Service
VR	Virtual Reality

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1. INTRODUCTION

Increasing people's adherence to Physical Activity (PA) through technology support remains an important research challenge. Over the past decade, the Human-Computer Interaction (HCI) research community and some commercial sectors have tried to tackle the challenge of increasing PA by using sensing devices for monitoring PA and providing motivational feedback [1], [2], mostly building on cognitive-behavioral theories [3]–[5]. However, technologies and related research provide very limited support for psychological barriers to PA [6]. Users, through these technologies, may realize their level of physical inactivity, but they are frequently incapable of acting on this problem by themselves, which undermines alterations in behavior and increases disappointment in users [7]. Among these psychological barriers that prevent people from engaging in PA [6], this thesis work focuses on those related to adults' body perception (BP). Negative or disturbed BPs are known to influence emotional state and movement functions [8], [9] and are also intricate in physical inactivity [8], [10]–[12].

Prior works in neuroscientific research have shown it is possible to exploit bottom-up multisensory mechanisms to alter BPs. This research has shown that our mental body-representation (that refers to a perceptual representation about what the body is felt to be like [13]) is highly malleable in response to changes in the incoming multisensory bodily information [14]–[16]. For instance, [17] showed that altering the naturally produced walking sounds (by augmenting the high-frequency spectral components) can lead to positive BPs, that is, by making people feel lighter during the movement, as well as influence people's emotional state and movement behavior.

An alternative approach to that of altering naturally produced sounds, and which also exploits **bottom-up multisensory mechanisms** related to BP, is interactive sonification. This approach is defined as the use of sound within a human-computer interface (e.g., a wearable device) to give auditory feedback about the interaction itself (e.g., body movement) [18]. **Interactive movement sonification** has been effectively used for sensori-motor learning [19], [20] and specifically to motivate, inform, and guide people on their movements during general PA and sports, (Cesarini et al., 2016; Newbold et al., 2017; Schaffert & Mattes, 2015) and physical rehabilitation [24]–[27]. For example, a study focusing on children with autism who need to improve motor skills, investigated the use of interactive sonification of side arm movements to impact these children's motor skills [24]. The results of this study showed that movement sonification with discrete sound structures makes children with autism more aware of their movements, and it helps them to perform their movements correctly.

This thesis presents a different and new approach, which exploits bottom-up multisensory mechanisms related to BP in combination with the use of interactive movement sonification (FIGURE 1.1), to address the psychological barriers to PA in physically inactive adults. This approach focuses on changing people's BP through real-time movement feedback based on sound.

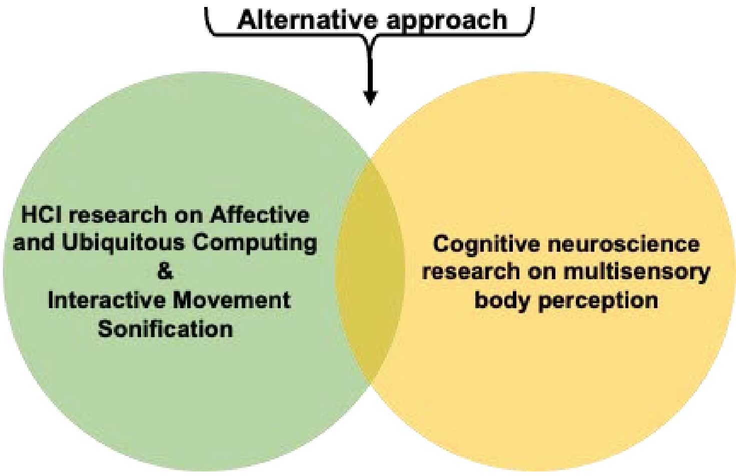


FIGURE 1.1: THE INTERSECTION OF THE AREAS OF INTERACTIVE MOVEMENT SONIFICATION AND COGNITIVE NEUROSCIENCE RESEARCH ON MULTISENSORY BP.

1.1 Motivation

Physically inactive lifestyle is one of the main reasons for health problems [28]. Globally, 28% of adults did not perform enough PA during the years 2001 to 2016. Moreover, 25% of women and 22% of men in Europe are not active enough [29].

One of the aims of the World Health Organization (WHO) is to support physically inactive adults in being active, by changing their "no activity" level to "some PA level" [28]. The basic strategies recommended by WHO for increasing PA in adults include incorporating in their daily habits recreational or leisure-time PA, walking as transportation, and planned physical activities with family or sports. By reviewing the available evidence, WHO concluded that for the global recommendation it is necessary to consider physical requirements, i.e., duration, frequency, intensity, type, and amount of PA [28]. The success of the recommendations depends on two interested audiences, the public health government, and physically inactive adults. Public health governments are responsible and the primary target audience in the development of guidelines for health-enhancing PA. However, how to develop these guidelines or approaches to overcome PA is a problem that still needs to be addressed.

For the WHO, the principal purpose of performing PA is to reduce the risk of diseases, such as heart, cancer, or hypertension [28]. Moreover, there is evidence that PA reduces symptoms of anxiety and depression [30]. However, the challenge is in how to help people to overcome those barriers that prevent their initiation or adherence to PA [7]. Those barriers or factors that prevent PA can be physical (e.g., limited mobility, age, pain), psychological (e.g., low mood, fear, low self-esteem), and personal (e.g., routines, friends, or work) barriers [6]. As mentioned above, the research presented in this thesis focuses on addressing the psychological barriers to PA, and in particular those related to BP, through technology.

Different research approaches combined with interactive technologies allow for investigating how technologies can be used to support PA. Such technologies integrate goal setting, monitoring of motor behavior, and feedback on PA. Heretofore, most work on technologies for facilitating PA adherence has focused on tracking body movements to increase awareness of PA [31]. Such tools have been designed to help adults in becoming more aware of their physical inactivity, but what is not yet clear is why with this knowledge adults are often unable to change behavior on their own [7]. However, it can be noted a lack of tools proposed to address such psychological barriers to PA or of tools focused on movement progress and endurance, or on giving good and rewarding personal experiences [7]. Previous works have identified that negative or distorted BP can affect self-esteem and emotional state (e.g., feelings of sadness), body feelings (e.g., feelings of being weak, inflexible, or incapable), and motivation for PA, and showed that body dissatisfaction is among factors undermining adherence to PA [30]. Therefore, individuals with low levels of PA find it defiant to start PA or accomplish adherence to PA (in the long and short term) [8], [10]–[12].

Considering the literature, there is a complementary novel approach proposed in [17] that exploits **bottom-up multisensory mechanisms** associated with BP to change BP and in turn, promote positive emotions and more active motor behaviors. Based on neuroscientific research showing BP alteration through sensory feedback [14], and in particular, through sound feedback [15]–[17], [27], [32]–[34], this work demonstrated that changing the natural sounds produced by one's body actions (in this case, the sounds of one's footsteps) can change BP (in this case, sense of one's body weight), and in turn emotional state and behavior linked to those body sensations. Another reasonable and emerging approach to tackle this issue could be **interactive movement sonification** [18], [35], [36]. This approach has shown the value of using sound as real-time sensory feedback on the body movement to guide or support the movement when performing PA, such as sports [21], [23], dance [37], or for rehabilitation of motor issues [26], [38], [39]. Beyond using interactive movement sonification for guiding or correcting movement [40], recent works [41] have used sound to give the sense of being capable or to lose the fear of performing the movement during physical rehabilitation of movement. This work, which focuses on people with chronic pain using a wearable device, uses interactive sonification to inform about the start, end and progression of the movement. The device is worn in the part of the body that is to be sonified, such as the arm or back, and uses an accelerometer and gyroscope to track users' body movements.

This thesis proposes to combine the two approaches above mentioned (interactive movement sonification and bottom-up multisensory mechanisms) with the goal to investigate the potential of inducing alterations in people's sensations of body capabilities and qualities of movement (e.g., flexibility and agility) in order to induce the feeling of being more capable of doing PA by using interactive movement sonification instead of transforming the natural sound made by one's body. Following this, the intention is to understand the potential emotional changes (e.g., bringing positive emotion to the body, motivation to perform PA, self-confidence) and then potential changes in behavior and motor patterns that these changes in BP elicited by sonification may bring in turn. The thesis does not engage with the idea of replacing medical assistance for inactive adults but to be a support for this target group.

1.2 Research questions

According to the problem identification (motivation) discussed in the previous section, physically inactive adults find it hard to start or keep adherence to PA because of psychological barriers associated with negative BP. Hence, this work intends to answer the main research question (RQ):

> *How can we use interactive movement sonification to promote physically inactive adults through alterations in body perception*?

This main RQ leads to the four following sub-questions that have been identified here along with the research methodology:

> **RQ1:** *What are the psychological barriers to physical activity related to body perception and what strategies can be used to overcome them by physically inactive adults?*
>
> **RQ2:** *Which movement sonification strategies, through changes in body perception, have the potential to support PA to overcome psychological barriers to PA?*
>
> **RQ3:** *How can we integrate movement sonification in wearable technology for PA and evaluate it in adults?*
>
> **RQ4:** *How can interactive sonification be used in the long-term and in everyday environments (i.e., in the wild) to promote physical activity in physically inactive adults?*

1.3 Objectives

In the previous section, the research questions aimed at addressing psychological barriers related to BP were considered. Following this, the objectives are defined according to the research methodology and to answer the research questions. A summary of the research questions, objectives, studies, and outputs is provided in FIGURE 1.3. It begins by defining the general objective:

> To change the body perception and address the psychological barriers related to physical activity, of physically inactive adults, using wearable devices and movement sonification.

Based on this general objective the following Specific Objectives (SO) were proposed:

SO1 - To *investigate* what barriers to PA are mentioned in studies oriented to the design and evaluation of technologies to promote PA, especially those related to BP.

SO2 - To *design* a portable device with a movement-sound palette to alter the BP, emotional state, and motor behavior patterns of physically inactive adults.

SO3 - To *evaluate* the short-term and long-term effect of the movement-sound palette on BP, emotional state, and motor behavior in studies with physically inactive adults.

1.1 Research methodology

In order to answer the research questions and objectives, this thesis followed the Design Science in Information Systems Research defined by Hevner et al. [42].

To carry out the research process the Design Science Research methodology structures and organizes it in three important fields (see FIGURE 1.2):

1. The Environment field is understood to be the user needs (stakeholders) derived from the problem.
2. The Design Science Research field focuses on building and evaluating the proposed solutions.
3. The Knowledge Base field aims to get to know, understand and advance scientific theories; expertise and experiences; and artifacts from previous research. Moreover, three cycles (Relevance Cycle, Design Cycle, and Rigor Cycle) allow the interaction between the three fields to find the best solution [43].

To connect these fields, there are three research cycles: Relevance, Rigor, and Design cycles. The general purpose of the Relevance and Rigor cycles is to provide knowledge gathered from the fields of, respectively, Environment and Knowledge base to the Design Science Research field. The Design cycle, as part of the research design science field, works on an iterative design and construction of a solution (artifact) that starts based on the knowledge provided by Relevance and Rigor cycles. A detailed description of how the fields and cycles were taken, will be presented in the Chapters 3. The Chapter 3 will present an adapted version of these after taking into account the research questions, the application domain requirements, and the research fundamentals (FIGURE 1.2).

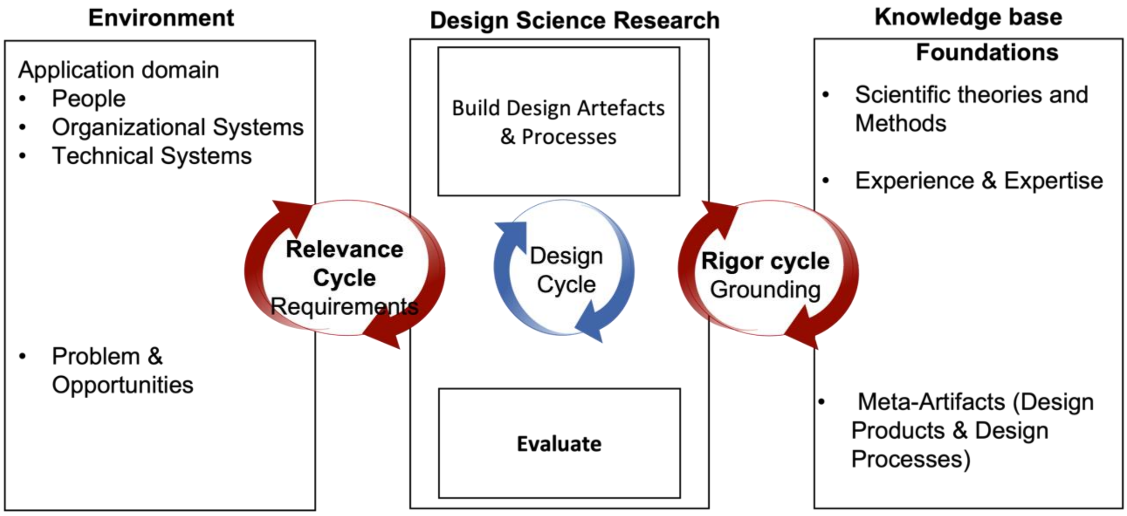


FIGURE 1.2: THE DESIGN SCIENCE IN INFORMATION SYSTEMS RESEARCH FOCUSES ON RESEARCH CYCLES [43].

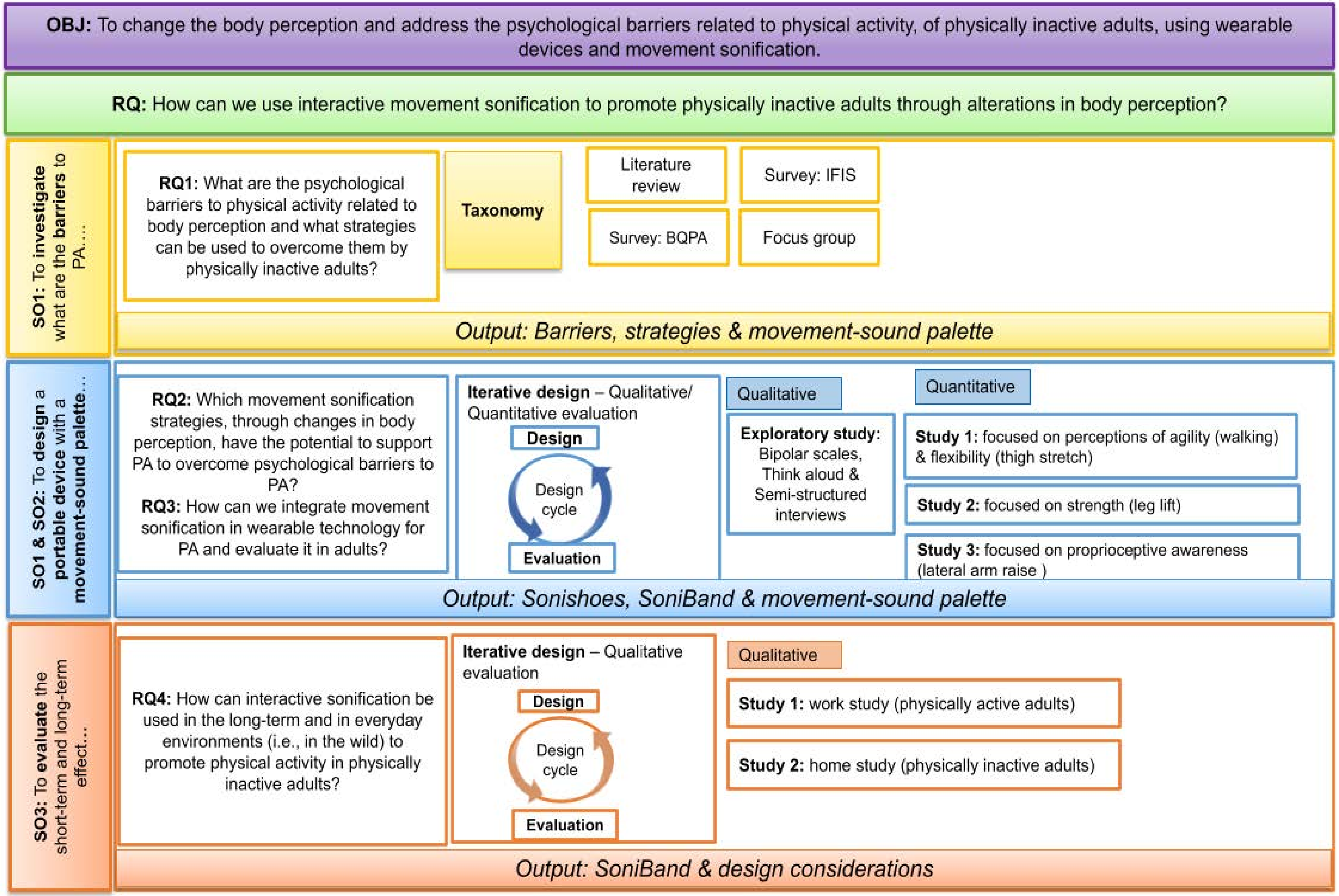


FIGURE 1.3: RESEARCH QUESTIONS, OBJECTIVES, STUDIES, AND OUTPUTS IN ITERATIVE DESIGN. TAXONOMY REFERS TO THE SYNTHESIS OF PSYCHOLOGICAL BARRIERS RELATED TO BP; BQPA REFERS TO BARRIERS QUESTIONNAIRE FOR PA [6]; IFIS REFERS TO INTERNATIONAL FITNESS SCALE [44]–[46]. PHYSICALLY INACTIVE ADULTS WERE THE PRIMARY STAKEHOLDER FOR THIS THESIS.

1.2 Contributions

This thesis is fundamentally concerned with and contributes to the fields of HCI, and cognitive neuroscience research. As a result of this work, the following contributions were expected:

(1) Contribution 1: A novel approach that combines interactive movement sonification and bottom-up multisensory mechanisms to address psychological barriers in PA.

(2) Contribution 2: A synthesis of psychological barriers to PA related to body perception in physically inactive adults and strategies to overcome them.

(3) Contribution 3: A set of use cases, the design, and use of movement-sound palettes (mappings) for specific movements recommended in PA programs.

(4) Contribution 4: A set of movement-sound mappings for sensing technology with the potential to alter BP to facilitate PA in the home.

(5) Contribution 5: A set of design guidelines for sensory technologies to inform future work on movement sonification to alter PA.

(6) Contribution 6: A wearable device for body monitoring and movement sonification, towards promoting PA.

(7) Contribution 7: An impact on society, economy, and the psychological wellbeing of adults.

1.3 Thesis outline

My thesis is organized as follows:

Chapter 2 contains the first part of the Knowledge Base field. It provides the background necessary for understanding the concepts of BP, sensory feedback, and research work on neuroscience to alter BP. Lastly, it introduces the notion that negative BP prevents PA.

Chapter 3 contains the second part of the Knowledge Base field. It is concerned with the methodology used in this thesis and Problem Identification. This chapter explains the research methodology and how it has been followed to analyze the problem. It allows us to understand the stakeholder, the problem, and the opportunities.

Chapter 4 contains the third part of the Knowledge Base field. It provides the state of the art driving this research. First, the work of technologies to promote PA is presented, together with an analysis of the technological tools used to promote PA, and their possible limitations in dealing with psychological barriers. Second, studies using auditory feedback for sport or physical therapy and neuroscience research showing that BP can be altered through sensory feedback, in particular sound, are presented. For example, the chapter details the use of movement sonification to guide/correct movement in people with chronic pain, and the potential of altering BP in this context (e.g., for feeling less fear).

Chapter 5 presents the design and development of the solutions based on the Knowledge Base and the identification of the problem. It shows the prototypes obtained in the research process. Moreover, the chapter describes the qualitative and quantitative evaluation of the proposed solutions.

Chapter 6 presents a first approximation, an exploratory study, to understand the use of movement sonification in adults during PA.

Chapter 7 presents various quantitative studies to evaluate the prototypes designed (movement-sound mappings and wearable devices) and understand the effects of the designed movement sonifications on body feelings and movement behavior.

Chapter 8 presents two qualitative studies that provide further insight into the reasons behind the effects observed in Chapter 7 and extract the sound qualities that affect people's emotions and body feelings. One of the studies was a long-term study (2 weeks) in a home context with physically inactive adults.

Chapter 9 provides a critique of the findings and discusses their implications for future research applied to different (e.g., long-term) scenarios through the proposal of design considerations.

Chapter 10 presents the conclusions of these thesis by providing a summary of the contributions, limitations, and future research.

2. BACKGROUND

This chapter presents the bases of psychology and neuroscience about human BP. In particular, this chapter provides background about human multisensory BP and the importance of BP during PA.

2.1. Human multisensory body perception

In psychology, **sensation** is defined as the awareness that results from the stimulation of sensory organs (i.e., eyes, ears, nose, tongue, and skin) [47]. **Perception** can be considered as the organization and interpretation of this sensory information or stimulus to represent and understand their environment [47]. Sensation and perception are always working together; once the stimulus is received from the environment, the information is organized in the brain, to finally make a **mental representation** of the stimuli, to allow us to make decisions or to adopt behaviors (consciously or subconsciously) based on that stimulus [48].

There are mostly five known senses - smell, sight, sound, taste, and touch - and a sixth sense, proprioception (knowledge of body position), used with the aim of obtaining sensory information [47].

In terms of auditory sensation and perception, the sound waves picked up by the ears are translated into neural impulses that are sent to the human brain, where they are integrated with experience and interpreted as the sounds we have experienced. The human ear is indeed sensitive to a diverse group of sounds, ranging from the soft tick of a clock in a close room to the rumble of a band in a nightclub, and humans have the ability to detect very small variations in sound. But the ear is especially sensitive to sounds of the same frequency as the human voice. A mother can distinguish her child's voice among a host of others [47], and when listening to the footsteps of a person walking, according to their characteristics, the footsteps can be identified as the footsteps of someone large or small, with a light or heavy gait [17]. Within a split second, the auditory system gets the sound waves, transfers the waves to the auditory cortex, compares them with knowledge stored from other sounds, and identifies the identity of the owner of the voice or sound [47].

On the other hand, how we feel about our body but also how we represent it mentally can change through time because of external signals [14], [49], [50]. Representations of body appearance known as "body image" (e.g., size or weight) should be distinguished from representations of body parts position and body kinematics, on which people rely whenever they move, reach for objects, or manipulate tools, known as "body schema" [51]–[53]. The latter component can also be subconscious and shape our body movement and interactions with the surrounding environment (e.g., [53], [54]). Together though, the various components of body-representations influence how people subjectively feel about their body and its physical capabilities (for instance, feeling light or strong) and about their movement (for instance, finding it easier or more comfortable), and this can, in turn, interact with one's emotional state [17].

Although the perception process is highly accurate, the perception can be fooled by an illusion: "*Illusions occur when the perceptual processes that normally help us correctly perceive the world around us are fooled by a particular situation so that we see something that does not exist or that is incorrect.*" [47]

In line with this, previous neuroscience research has shown that our body representation is highly malleable and continuously updated by the sensory feedback [55], [56]. For instance, a well-known "Pinocchio" illusion is an often-mentioned illustration of how flexible the representation of the body can be in response to synchronous multi-sensory information. To induce this illusion, participants touch their noses while physiotherapy vibrators are placed on the participants' biceps tendon [57]. The "Pinocchio" illusion demonstrates that through the sense of touch and vibration stimuli it is possible to induce the illusory sensation of one's arm being stretched, thus causing the perception of the hand's position in space to be altered. There are several experiments like the previous one to study other possible illusions, such as the "Rubber-hand illusion" [14], [58]. This illusion consists of a rubber hand placed on a table in front of the participant next to his/her real hand, which is always hidden; the participant receives (synchronous and asynchronous) stimulation with a paintbrush until he/she perceives the false hand as the real hand. Such research has shown that the mental representation of one's body in relation to several features (e.g., body size, weight, body parts location) depends on external inputs from a broad range of sensory modalities, such as visuo-tactile stimulation and proprioception.

Following this, external inputs are classified or distinguished as bottom-up processing and top-down processing. On one hand, the bottom-up processing begins with incoming stimulus, like visual or touch, gathered from the external environment, including sound signals [15], [16], [59]. On the other hand, the top-down processing refers to processing that is based on knowledge, such as memories, experience, and expectations, which can shape perception. For example, in a study with footstep sounds it was found an interaction between sound condition and "wish to be more femenine/masculine" in the observed effects [33]. Those works showed that it is possible to exploit bottom-up and top-down multisensory mechanisms related to BP to produce illusions of changes in the body.

2.2. Altering BP through sound and technology

There is much less work on sound as a source of sensory alteration of one's own BP, as compared to work on other sensory modalities such as vision and touch. Recent research works have shown that by manipulating the sounds produced by one's own body movements, it is possible to alter BP and, in turn, the related emotional state and motor behavior [15], [17], [59]. For instance, a recent work [33] describes how altered footstep sounds can change BP during exertion exercises. Note that for such changes to happen sound feedback needs to be felt as generated by one's body [60].

The first evidence of self-produced sounds altering body representation is in [15]. This work presents an experiment where participants tap their hand on the floor and they listen to the resulting sounds originating at the same location where they tapped (zero distance condition), or sound originated at double the distance (double distance) or sound at four times the distance (quadruple distance) where they tapped (see FIGURE 2.1). Participants' perception of arm length was evaluated with a tactile distance task, they extended their right arm sideways and they heard the sound in synchrony with each tap. Results showed that the spatial manipulation of the sounds generated when the hand taps on a surface in the double distance condition leads to perceiving one's arm as longer than before being exposed to such experimental manipulation. Based on the previous work, two follow-up studies showed the conditions for these changes to occur [59] as well as effects on arm movement [61]. [59] focused on investigating the role played by agency and kinesthesia in changing the mental representation of arm length. Two experiments were performed in which the participants tapped a surface with their arm while extending their arm. (1) The sense of agency was presented when the tapping sounds were in synchrony or asynchrony with the real tapping. (2) kinesthetic cues indicate a change in location of the hand, i.e., the participants did not extend their arm but tapped near (Experiment 1) or far (Experiment 2) from the torso of their body. As result, in both experiments there was a change in the tactile distance when they tapped and listened to the sound with a double auditory distance, this suggested an effect on the feeling of arm length. Both, sense of agency and kinesthetic cues were necessary to induce these changes.

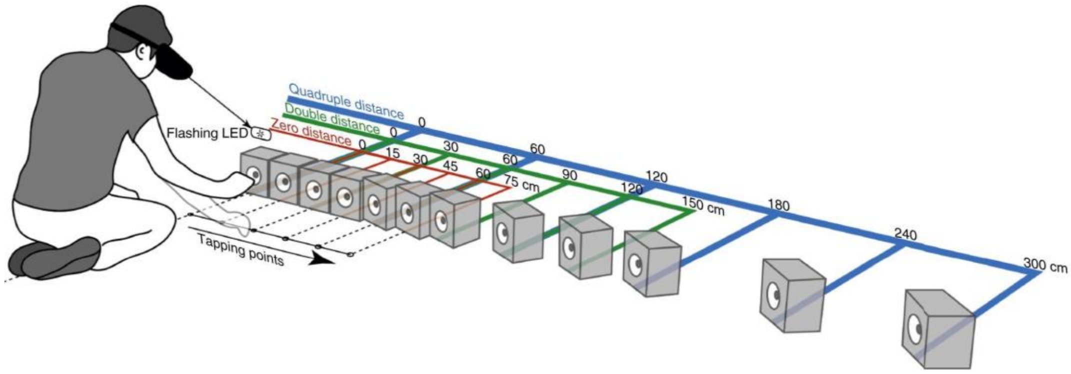


FIGURE 2.1: ILLUSTRATION SHOWS THE EXPERIMENTAL SET-UP OF [15].

A related study employed a prototype with a sonic interactive surface. The prototype allows to produce (pre-recorded) auditory signals related to the applied tapping force with three different levels of force: weak, medium, and strong. Results showed changes in the perception of one's own tapping ability and changes in the tapping force across the different sound conditions. Furthermore, with changes in strength-related sound (e.g., increasing volume or frequency) there was also a change in emotional state and perceptual aspects (perceived surface hardness) [62].

Building on this, there are other works showing that artificial sounds that are not associated with one’s body or one’s body movements can also bring changes in BP [16], [34], [63]. For example, [16] performed two experiments involving finger pulling and ascending, descending, and constant tonal sounds; FIGURE 2.2. The prototype consisted of a pressure sensor that detected the finger being pulled and simultaneously triggered a sound. Results showed that playing an ascending tone while people pull the finger can lead people to perceive their own finger as being longer than with the descending or constant sounds.

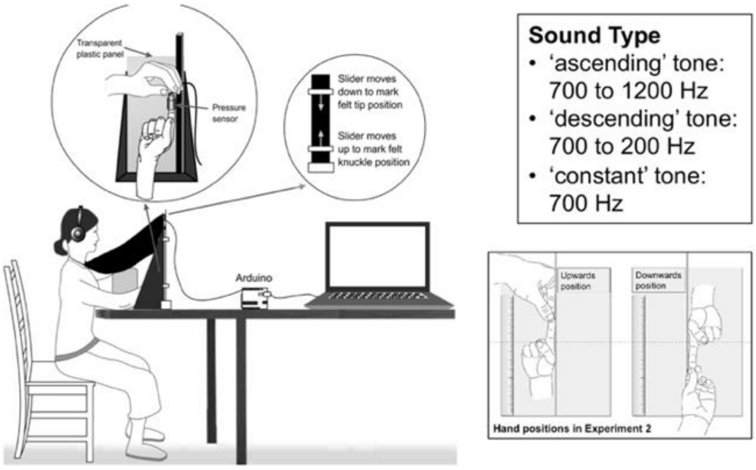


FIGURE 2.2: OVERVIEW OF THE EXPERIMENTAL SETUP AND DESIGN, AN EXAMPLE OF PULLING THE FINGER [16].

Lastly, [34] also conducted two experiments. Experiment 1 was the classic Rubber Hand Illusion (synchronous and asynchronous touches) while experiment 2 included the conditions auditory cues (a/synchronous touches with a/synchronous auditory cues). Results showed that the rubber hand illusion was significantly greater in the synchronous touch condition with synchronous auditory cues than in the synchronous touch condition with asynchronous auditory cues, thus demonstrating the contribution of the auditory cues to the changes in BP.

The experiments described above present evidence that artificial or natural sounds produced when interacting with surfaces or touching one's body can affect BP and behavior. However, little is known about the effects of sounds that accompany the movement of a limb (i.e., at its beginning/end or during movement) on the perception of our own body, emotions, and motor behavior.

2.3. Negative body perception and physical activity

PA is known to be influenced by various psychological factors [6]. In addition, humans can have positive and negative perceptions of one's body [6], [41], [64]. Positive BP refers to accepting, respecting, and loving all the aspects of one's own body. Therefore, negative BPs refer to dissatisfaction and not accepting some or all of the aspects of one's own body [64]. For example, one may have the perception of poor body capabilities or body image, both related to psychological factors. An important example of feeling a lack of body capabilities can be seen in persons feeling incapable or weak to perform PA, even with fear [12], [25], [41]; a notable example of poor body image is persons with eating disorders [65]. Unfortunately, negative perceptions of the body are considered to be the best predictor of the lack of adherence to PA [10], [11]. Previous research provides evidence of the existence of psychological barriers to PA related to BP in different populations, such as in people with overweight, as shown by [66] that reported weight perception by people with overweight as one of the barriers to PA; or people with chronic pain [27], [41] feeling fear or incapable to perform PA. In particular, PA is known to be influenced by various psychological factors [6], including negative perceptions of one's body [6], [27], [41]. The focus of this thesis is on addressing the problem of physical inactivity in people by tackling those psychological barriers related to BPs through the induction of changes in people's BPs, and in turn, in their emotional state and motor behavior.

In this thesis, psychological barriers to PA were identified through a taxonomy based on three sources of information - a literature review [6], a focus group of experts, and surveys (BQPA [6], IFiS [46]) - see Chapter 5. This led to the identification of the following most relevant psychological factors related to BP that affect PA:

- Confidence in one's body: how confident a person is in their PA abilities, or how much bodily satisfaction they have during the activity.
- Perceived body appearance: Self-esteem related to PA, subjective importance of corporality; Physical attractiveness; and Care of physical appearance
- Perceived body capabilities: perception of one's body cardiorespiratory endurance, muscular strength, body flexibility, speed, and agility.
- Perceived movement progress: sense of progress/achievement and sense of absolute limits/measure against yourself.
- Other barriers are related to bigger barriers (i.e., Confidence in one's body and perceived movement progress) which are related to the confidence or poor sense of control during a movement or to keep a position, however, they can be addressed individually:
    - Sense of lack of balance.
    - Sense of feeling stuck.

In addition to this, it is important to consider emotional aspects associated with PA linked to these factors, which are most usually described in terms of anxiety or frustration when users may become more aware of their problems (e.g., physical inactivity or capabilities) and are not able to act on them on their own [7].

Chapter 5 introduces the psychological aspects/barriers related to BP and PA that have been found in the area of psychology and computer science and works showing how current technologies to promote PA do not address important psychological barriers that undermine the desired behavior, such as the low perceived self-efficacy and body dissatisfaction [27], [41]. It is important to understand the psychological aspects of PA and to integrate them into the design of technological solutions to increase PA. Therefore, this thesis aims to integrate into the design of technologies for PA the variables affecting PA, including barriers or facilitators for doing PA related to BP.

2.4. Chapter Summary

This chapter introduced the concepts of psychology and neuroscience about human BP, and how it is possible to alter BP through sound and technology, as well as the negative BP that prevents PA. Here then is presented the concepts of sensation and perception that work together to create a mental representation of the stimulus received.

Body representations are indeed very malleable and they can be altered through sensory cues [17], [33]. While there is more research on changing BP through visual and tactile, little research is focused on sound as a source of sensory alteration of one's own BP, mainly in assisting the movement of the limbs. Bottom-up and top-down multisensory mechanisms have the potential to address the psychological barriers that affect people with a low level of PA and to improve physically inactive lifestyles.

Building on the background of neuroscience, research work to alter BP, and how negative BPs affect PA, the next chapter presents the research methodology and details the problem identification. In doing so, this thesis aims to address this gap, that is, how to design a technology that takes into account the psychological barriers related to negative BP and PA.

3. RESEARCH METHODOLOGY AND PROBLEM IDENTIFICATION

This chapter presents a Design Science Research Methodology adopted to design and build proposed solutions based on the inputs from the problem Environment (e.g., requirements and needs of the user) and Knowledge Base. The inputs allow for identifying the problems and the general approach to design the solutions, in iterative cycles. The inputs also guide the first steps of the research methodology through the research cycles (Relevance and Rigor), which are then gradually refined to the proposed solutions (by Design cycle).

3.1. Research methodology

This thesis has been structured following the Design Science Research methodology by [43]. The different phases of this research work (problem identification, research questions, objectives, etc.) were structured through the fields of the methodology (Environment, Knowledge Base, and Design Cycle).

Hevner et al. [42] present seven guidelines for design science to assist researchers in understanding the requirements of the solutions. These guidelines stipulate that there must be a (1) solution and a (2) relevant problem that could be solved with the proposed solution. Once a first version of the solution is designed, (3) the next step is a design evaluation to refine the solution and provide feedback demonstrating its utility, quality, and efficacy. The design evaluation provides evidence of the solution that (4) contributes to two areas, Environment and Knowledge Base. The research of the Environment aims to generate an artifact that can be applied in the real-world usage scenario and evaluated in terms of its ability to satisfy stakeholders. Research of the Knowledge Base aims to contribute ideas of design (e.g., guidelines) and methods (e.g., use cases) for the Knowledge Base to evaluate a proposed solution based on the design problem. (5) This relies upon the application of rigorous methods with appropriate data collection (e.g., questionnaires, sensors) and analysis techniques (ground theory, statistics) to create the solution. In addition, (6) the solution must be considered inside of a search process to satisfy the requirements and solve the boundaries of the problem environment. Finally, (7) it is necessary to communicate the research to interested audiences, i.e., technology-oriented as well as management-oriented so that they understand the design process that the solution goes through.

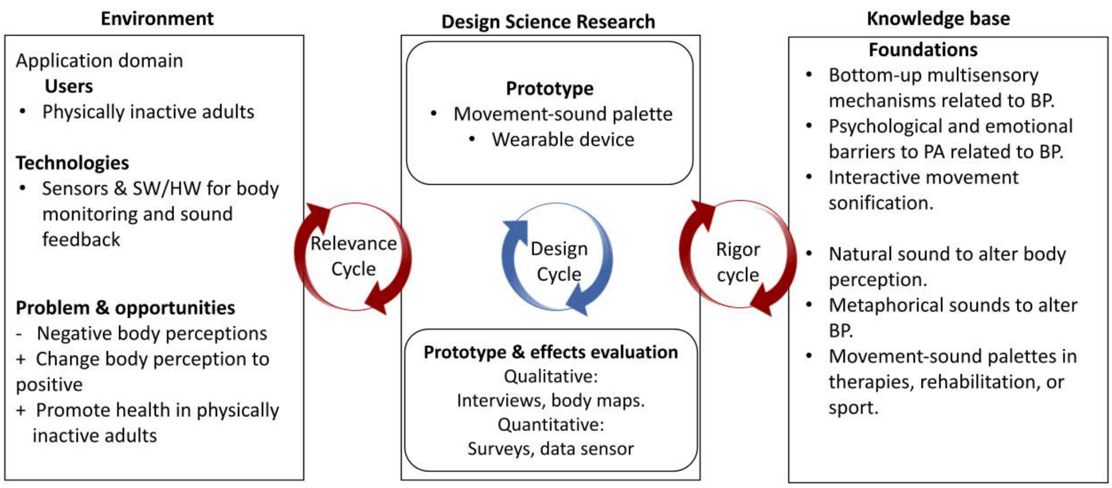


FIGURE 3.1: THE DESIGN SCIENCE RESEARCH METHODOLOGY BY [43] WAS ADAPTED FOR THIS THESIS. THIS FIGURE SPECIFIES EACH CATEGORY PRESENTED.

The Design Science Research methodology structures and organizes the seven guidelines into three important fields (see FIGURE 1.2): the Environment field (stakeholders), the Design Science Research field (building and evaluating), and the Knowledge Base field. Moreover, three cycles (Relevance Cycle, Design Cycle, and Rigor Cycle) allow the interaction between the three fields to find the best solution [43].

The Relevance Cycle consists of providing the requirements (as inputs) to the Design Science Research about the application domain such as users, technical knowledge, problems, and opportunities. Moreover, the Relevance Cycle allows for studying and evaluating the proposed solution in the Environment, in order to know whether the results (as output) of the current solution improve the environment of the stakeholders (physically inactive people). The Rigor Cycle aims to provide the foundations for the field of Design Science Research, such as definitions, new approaches, scientific theories, and methods. Once the research has been carried out the cycle allows adding all the new experiences or techniques into the Knowledge Base. The Design Cycle allows to design, construct, and evaluate a proposed solution based on the information provided by the Relevance Cycle and Rigor Cycle. The results of the iterative evaluations will guide the investigation to refine the solution or to carry out further iterations to obtain more feedback. Based on the Methodology and its research cycles, the next sections in this Chapter present an adapted version taking into account the research questions, the application domain requirements, and the fundamentals (see adapted version in FIGURE 3.1).

This Methodology allows for identifying the objectives and research questions derived from the analysis of the Environment and Knowledge Base. The Knowledge Base of this research (Chapter 2, Background) included cognitive neuroscience literature on "human multisensory perception and BP", sensory-driven body illusions "altering BP through sound and technology", and "negative BP and PA". Further, Chapter 4 contains State of the art including HCI works on "technologies for PA"; "psychological factors that facilitate or prevent PA"; "physical and personal factors that prevent PA"; "audio feedback to facilitate sport, dance, and motor therapy"; and "movement sonification for altering body and movement perception". As part of the Environment field, for this thesis work, the stakeholder (physically inactive adults) and technologies currently used to support or monitor PA were identified and considered with the aim of use during the prototype design phase. The Design Cycle involved designing and building prototypes and evaluating them through qualitative (e.g., interviews) and quantitative (e.g., survey, sensors) methods. A detailed description of how the cycles were taken, will be presented in the next chapter (Section 5.3) at the time problem identification is defined through them.

3.2. Relevance cycle: survey study

Each research sub-question is part of an iteration in the Design Cycle, while the objectives represent a step to the understanding, development, and functioning of the solution to contribute to both fields. The Relevance Cycle relates to the research environment and the ongoing research. In its first phase (SO1 and RQ1), this cycle provides the research with information about the environment, the people, the organizational system, and the technology currently in use in the domain to be researched. This information is the basis on which to identify existing problems and opportunities on which the research can focus. Later, at a more advanced stage of this cycle, it will provide an environment for conducting evaluations. Once the research has been completed and some issues have been solved or mitigated, the people in these environments can benefit from the knowledge and artifacts developed.

3.2.1. Stakeholders: user profiles

In the case of the present thesis, data from a survey study was obtained to create a user profile according to the PA level in a population of Spanish adults, and specially to characterize those adults with low PA level. This survey study was performed as part of a bigger project (MagicShoes project) which provided the framework for this thesis, and thus was not part of this specific thesis work. This survey study aimed to identify the psychological barriers to PA experienced by people as well as other psychological factors influencing people with low PA levels. The survey data were collected online in 2018 through a dedicated online panel. The sample included all age ranges of adults in a representative proportion of the Spanish adult population and the various Spanish regions, and it was gender-balanced. The age groups were structured as follows: from 18 to 24, from 25 to 34, from 35 to 44, from 45 to 54, from 55 to 64, from 65 to 74, and 75 years or older. The final sample involved 876 participants.

876 adults, between 18 and 74 years of age (*M* = 45, *SD* = 16.17), 49.8% were men (n = 436) and 50.2% women (n = 440). The participants were divided into three groups based on the *International Physical Activity Questionnaire Short Form* (IPAQ-SF) [67], version in Spanish Appendix A) which measures the level of PA according to the time spent in vigorous and moderate activities, as well as the spent time walking and sitting, measured through the Metabolic Equivalent of Task (MET) see TABLE 3.1.

59.5% of participants were considered to have a high level of PA (n = 521) of which 49.14% were men (n = 57) and 50.86% were women (n =59). 27.3% of participants showed a moderate level of PA (n = 239), of which 50.2% were men (n = 120) and 49.8% were women (n =119). Finally, 13.2% of participants showed a low level of PA (n = 116), of which 49.1% were men (n = 57) and 50.9% were women (n = 59).

TABLE 3.1: CHARACTERISTICS OF SURVEY PARTICIPANTS. GROUP 1 = LOW LEVEL OF PA, GROUP 2 = MODERATE LEVEL OF PA, AND GROUP 3 = HIGH LEVEL OF PA.

	Group 1[a]	**Group 2[a]**	**Group 3[a]**
Total of participants	116 (13.2)	239 (27.3)	521 (59.5)
Gender (male/female)	57/59	120/119	259/262
Range of ages			
18-24	17 (14.7)	32 (13.4)	78 (15)
25-34	20 (17.2)	45 (18.8)	85 (16.3)
35-44	26 (22.4)	49 (20.5)	81 (15.5)
45-54	19 (16.4)	36 (15.1)	94 (18)
55-64	26 (22.4)	29 (12.1)	87 (16.7)
65-74	8 (6.9)	48 (20.1)	96 (18.4)
Employment situation			
Employed	67 (57.8)	133 (55.7)	273 (52.3)
Unemployed	17 (14.7)	31 (13)	65 (12.5)
Student	19 (16.4)	22 (9.2)	52 (10)
Retired	8 (6.9)	50 (20.9)	105 (105%)
Others (housewife, freelance)	5 (4.3)	3 (1.3)	26 (5)
Working time	32.7 (SD=14.73)[b]	35.6 (SD=13.4)[b]	33 (SD=14.89)[b]

a. Notes: number of participants in each category; percentage (%).
b. Notes: hours, standard deviation (SD).

The criteria to analyze the stakeholders was also the International Fitness Scale (IFiS, see Appendix B) [45][1]; this questionnaire allows people to self-measure their level of PA, and for the purpose of the thesis, how people's perception of their own fitness is an important point to know if there is a lack of confidence in their physical capabilities, such as perception of general fitness, cardiorespiratory endurance, muscular strength, speed/agility, and flexibility. The IFiS uses Likert-type response items with choices varying from *1 = very poor to 2 = poor, to 3 = average, to 4 = good, to 5 = very good.*

The median and range of the question response scores in participants with low level of PA for the different fitness scales were: general fitness: median= 3 (with a range of 1 –

[1] http://profith.ugr.es/IFIS

4), cardiorespiratory endurance: 2 (1 – 5), muscular endurance strength: 3 (1 – 5), speed/agility: 3 (1 – 5), and flexibility: 3 (1 – 5). In the case of participants with a moderate and high level of PA, both types of populations reported perceiving themselves as having an average level of physical fitness, 3 (1 – 5), as well as cardiorespiratory endurance, muscular strength, speed/agility, and flexibility. Here it is observed that people with low, moderate, and high levels of PA perceive similarities with each other in terms of having a perception of an average level of PA, although people with a low level of PA show differences in the perception of poor cardiorespiratory endurance. The previous findings showed the utility of the IPAQ to identify stakeholders for the design of BP-related PA management barriers, but it is complemented with IFiS to know how they perceive their own bodily capabilities.

With regards to their employment situation, most of the participants with an inactive lifestyle were full-time employees (n = 52; 44.8%). Other participants were students (n = 19; 16.4%), unemployed (n=17; 14.7%), part-time employees (n=9; 7.8%), retired people (n=8; 6.9%), or others (n=5; 4.3%). The mean working hours per week for the sample were 32.68 hours (SD = 14.73).

The information provided by the survey shows that people with a low level of PA tend to perceive themselves as having an average or below-average level of physical fitness. Moreover, it shows that most of the participants were full-time employees.

A Barriers Questionnaire for PA (BQPA) was part of the survey study [6]. The BQPA is a tool that allows identifying the barriers people experience to engaging in PA. The BQPA contains 63 5-point Likert-type response items (*Never = 0, Sometimes = 1, Often = 2, Many Times = 3, Always = 4*) allowing the reporting of possible obstacles that can be encountered when doing PA. 14 (11 psychological and 3 physical) items refer to barriers PA related to BP. These items were considered of special relevance to this thesis work since they take into account the body sensations during PA, and could help in the design considerations of the prototype for PA. See the items and responses in TABLE 3.2.

Around 25% (between 22.4% and 29.3%) of physically inactive people reported not engaging in PA because sometimes: they did not like feeling aware of their own body when doing exercise; they did not feel in shape; they did not feel aware whether their body posture was proper when exercising; they did not notice any improvement in their body; they felt stress for some reason; or they felt frustrated when trying to do exercise.

About 30% (between 31% and 36.2%) of physically inactive people reported that some of the obstacles that prevented them from doing PA are because sometimes: they felt uncomfortable with their body; they did not know the technique to do some particular exercises; they usually felt tired, very tired, or lazy to exercise; they did not feel capable; they felt pain when exercising; or they did not feel in the mood. Additionally, an item in the questionnaire not related to BP showed that physically inactive participants reported not having a habit of exercising (Never (n=25; 21.6%), Sometimes (n=27; 23.3%), Often (n=21; 18.1%), Many Times (n=20; 17.2%), Always (n=23; 19.8%)).

These survey results allowed us to see the barriers that may interfere with the PA of the stakeholders, who could use the prototype. This is relevant in terms of the design and development of the prototype, as the results provided an understanding of the psychological barriers to PA related to BP. For example, for stakeholders who don't like to feel self-aware when exercising, or that don't feel capable of exercising; the challenge is to design a technological device, that can change the perception of their body and in this case, body awareness. Research is needed to explore whether a new type of sensory feedback (for example, sound) can help stakeholders to have a positive perception of their body, creating body sensations such as fluidity or control of their movements during PA.

TABLE 3.2: 14 ITEMS WERE SELECTED FROM THE BQPA QUESTIONNAIRE AND THEIR VARIABLE CORRESPONDENCE.

Num.	Variable correspondence	Item	Results
1	Self-confidence/self-esteem	I feel uncomfortable with my body.	Never (n=35; 30.2%), Sometimes (n=38; 32.8%), Often (n=17; 14.7%), Many Times (n=17; 14.7%), Always (n=8; 6.9%).
2	Knowledge	I don't know how to do some particular exercises, e.g., Using gym machines, swimming techniques.	Never (n=35; 30.2%), Sometimes (n=37; 31.9%), Often (n=20; 17.2%), Many Times (n=13; 11.2%), Always (n=8; 6.9%).
3	Energy level	I'm usually tired.	Never (n=18; 15.5%), Sometimes (n=44; 37.9%), Often (n=12; 20.7%), Many times (n=18; 15.5%), Always (n=12; 10.3%).
4	Energy level	I feel very tired to exercise	Never (n=17; 14.7%), Sometimes (n=39; 33.6%), Often (n=12; 20.7%), Many times (n=20; 21.6%), Always (n=8; 8.6%),
5	Awareness	I don't like feeling aware of my own body when doing exercise.	Never (n=50; 43.1%), Sometimes (n=26; 22.4%), Often (n=21; 18.1%), Many Times (n=10; 8.6%), Always (n=4; 3.4%).
6	Discipline, Initiative, willpower, and commitment	I feel lazy to exercise.	Never (n=13; 11.2%), Sometimes (n=38; 32.8%), Often (n=15; 12.9%), Many Times (n=26; 22.4%), Always (n=22; 19.0%).
7	Self-efficacy	I don't feel capable.	Never (n=42; 14.7%), Sometimes (n=33; 33.6%), Often (n=12; 20.7%), Many Times (n=20; 21.6%), Always (n=8; 8.6%).
8	Fitness status	I'm not in shape.	Never (n=20; 17.2%), Sometimes (n=30; 25.9%), Often (n=23; 19.8%), Many Times (n=28; 24.1%), Always (n=13; 11.2%).
9	Pain or body sensations	I feel pain when exercising.	Never (n=33; 28.4%), Sometimes (n= 42; 36.2%), Often (n=21; 18.1%), Many Times (n=16; 13.8%), Always (n=4; 3.4%).
10	Awareness	I am not aware whether my body posture is proper when exercising.	Never (n=28; 24.1%), Sometimes (n=34; 29.3%), Often (n=22; 19%), Many Times (n=20; 17.2%), Always (n=7; 6%).
11	Health/weight benefits	I don't feel my body being better when I exercise.	Never (n=55; 47.4%), Sometimes (n=26; 22.4%), Often (n=12; 10.3%), Many Times (n=13; 11.2%), Always (n=5; 4.3%).

12	Emotional/psychological state	I'm under some kind of stress	Never (n=46; 39.7%), Sometimes (n=29; 25%), Often (n=16; 13.8%), Many Times (n=22; 19%), Always (n=2; 1.7%).
13	Emotional/psychological state	I'm not in the mood.	Never (n=31; 26.7%), Sometimes (n=39; 33.6%), Often (n=25; 21.6%), Many Times (n=16; 13.8%), Always (n=5; 4.3%).
14	Challenge and difficulty	I feel frustrated when trying to do exercise.	Never (n=45; 38.8%), Sometimes (n=30; 25.9%), Often (n=16; 13.8%), Many Times (n=16; 13.8%), Always (n=5; 4.3%).

In terms of their use of technologies, "inactive" participants reported being familiar with the use of a smartphone (n = 107; 92.2%) and knowing how to use applications or games in the device (n =95; 81.9%). Similarly, they reported using social networks (n =107; 92.2%), e.g., Facebook, Twitter, or Instagram, for performing PA, as well as web pages (n =105; 90.5%), and forums and/or groups (n = 110; 94.8%). Participants reported using the smartphones/tablets for supporting their PA (n = 97; 83.6%) through their use of mobile applications (n =93; 80.2%), and they reported receiving feedback on PA performance through the use of an activity wristband (n = 101; 87.1%); additionally, they reported using Wii/Kinect/games of PlayStation (n = 110; 94.8%), but just a few used controls based on motion (n =10; 8.6), such as Wii (n = 5.8; 5%), Wii and Kinect-just dance (4). Lastly, participants reported using videos, e.g., on YouTube, to perform PA (n =93; 80.2%). Based on these survey results it can be concluded that end-users who wish to use the prototype will have basic technological knowledge and that they use technologies for performing PA. This is relevant in terms of considering their participation in studies involving the use of the technological prototypes designed. For example, they will know how to handle mobile applications or web pages with which they will have to interact in specific situations, such as in controlled studies or in wild environments. This is also relevant when thinking about the potential appropriation of this technology.

3.3. Rigor cycle

This cycle is responsible for linking the current knowledge base with ongoing research. Its main purpose is to provide knowledge that is already known and has been demonstrated in previous scientific research. This cycle will provide the research with theories and research methods that provide a sound scientific basis for the research and a knowledge base of previous experience in the area to be addressed. Once the research yields results, the knowledge generated is summarized and it adds to the knowledge base for future research.

In the specific case of this thesis, this Knowledge base is composed of the research works described in Chapter 2 (Background), Chapter 4 (State of the Art), and the following Chapter 5 along with the first iteration of the Design cycle. Section 3.3.1 describes the literature review process, such as the criteria for selecting the literature of interest for this thesis work.

As for the contribution phase to the knowledge base, this new knowledge will be carried out through the present thesis, which will be summarized in Chapter 10 (Conclusion) and the set of articles already published.

3.3.1. Literature review in ACM about technologies for PA

3.3.1.1. Search strategy

For the literature review, this thesis has used the Association for Computing Machinery (ACM) digital library database, which gathers the compilation of all ACM publications (ACM Digital Library. URL: https://dl.acm.org/). ACM is recognized as the largest educational and scientific computing society in the world (Advancing Computing as a Science & Profession. URL: https://www.acm.org). This digital library database was searched for the terms "physical inactivity" "physical activity" "physically inactive" "physically active" "physical activities" "motor activity" "sedentary" in the title as well as in the abstract but discarding the mention of "children" and "kids". In the full text of the article was searched the occurrence of the terms: "barriers", "facilitators" or "needs". The literature review was restricted to articles published between 2014 to 2021. A first search was performed between 2014 to 2019 and the search was updated to 2021 (i.e., 01/01/2014 to 07/31/2021), articles written in English, on studies conducted with adult human participants (aged 18 years and older), see FIGURE 3.2.

3.3.1.2. Selection process

For the filtering process, an Excel table was used which included the name of the publication, the names of the authors, and the year of publication. The paper selection consisted of three stages. The first stage was to scan all the titles and abstracts of the papers collected through the search. Any papers that matched any of the exclusion factors were excluded. If it was ambiguous to see whether an article matched any of the exclusion factors, the article passed to the next stage as an included paper. The second stage involved a quick read of the full text of the remaining papers, scanning for significant features, those listed in the search strategy. Again, any papers that matched any of the exclusion factors were excluded, and those that were also not clear were handled as included papers in the final stage. The remaining articles were read extensively and in-depth in the third stage. Throughout this extensive reading, all relevant information on population aspects, methodology characteristics, and reported aspects affecting the PA of each paper were sorted and included in the table. During the careful reading, some papers were also identified as fulfilling some of the exclusion factors, therefore the papers were excluded from the final group of papers.

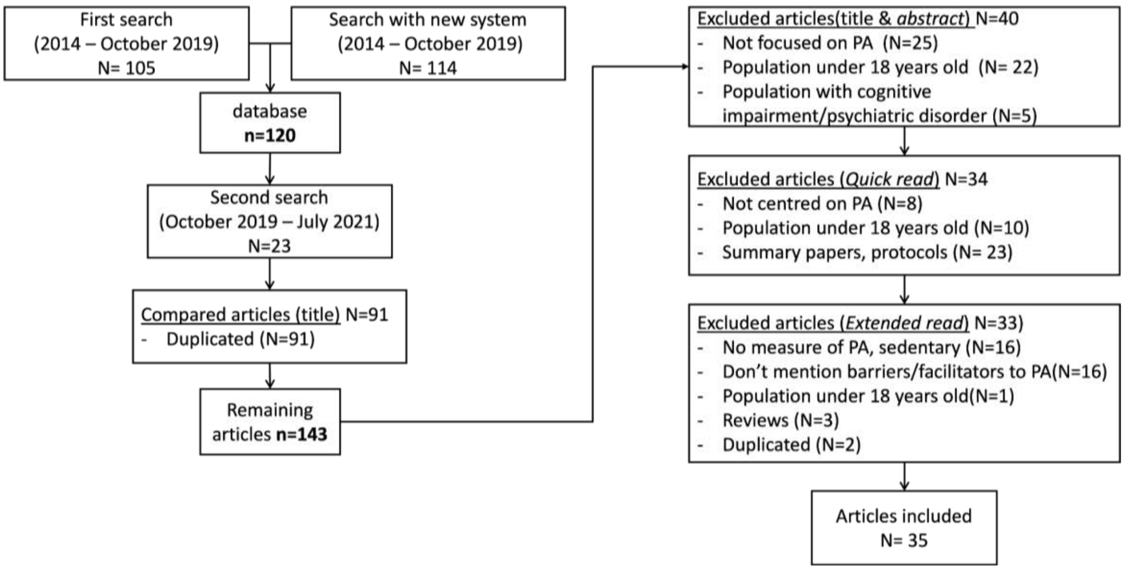


FIGURE 3.2: FLOW DIAGRAM EXPLAINING THE STRATEGY FOR THE SELECTION OF PAPERS IN THE REVIEW OF THE LITERATURE.

The literature review of the ACM database returned 143 articles. FIGURE 3.2 shows the flow diagram illustrating the selection process. By scanning the title and abstract, 40 articles were removed, resulting in 103. By quick reading of the full text, a further 34 papers were removed, resulting in 69. Lastly, by an extended reading of the full text, a further 33 papers were removed. The final group comprises 35 papers. The reasons for exclusion at each stage are shown in the flow diagram in FIGURE 3.2.

The papers gathered through the literature review process were used to inform about the barriers and facilitators of PA. The particular way of organizing the variables is based on a framework presented in [6], [68], which is adjusted to the variables identified in this research. Thus, the most important categories used here to structure the variables are as follows: psychological (emotional, motivational, or Priorities), physical (Medical Status), and personal/contextual (Work/Studies, Family/Social/Animal responsibilities).

3.4. Design cycle

Following both cycles, the information obtained allows iterating between two phases through the Design Cycle: the design and evaluation of the solution. In the next chapter (Chapter 5), the focus is on the design phase and on presenting the details about the solutions (strategies and mappings sounds), how it was designed and created; as well as on the Evaluation phase, explaining how the evaluation of the solutions started. Chapters 6, Chapter 7, and Chapter 8 present the quantitative and qualitative evaluations allowing to refine the solution proposed in Chapter 5.

3.5. Chapter Summary

This chapter presented the overview of the research methodology used in this thesis to address the objectives and research questions in this thesis. This chapter started by presenting the methodology (the three fields and research cycles) and how it was chosen based on its suitability to answer the specific objectives and research questions. The relevance cycle allowed us to describe the stakeholders and their profiles, the more relevant psychological barriers to PA, and their level of experience in the use of the technology. The Rigor cycle described the process of the literature review in ACM, search strategy, and selection process. Lastly, the Design cycle introduced the approach taken by this thesis to design and develop the studies to answer the general objective.

From here, the thesis presents, State of the art, Proposed solutions, Exploratory study, Quantitative evaluation, and Qualitative evaluation. The "State of the art" will allow for building the Knowledge base about the technologies and how they support PA in the literature review. Once familiar with the literature, the "Proposed solutions" chapter will present the first iteration of the possible solutions and to answer the **RQ1**. The "Exploratory study" will present the first study designed to answer the research question **RQ2**. "Quantitative evaluation" will present three controlled studies designed to answer the **RQ3**. "Qualitative evaluation" will present the two qualitative studies with physical active and inactive populations designed to answer the **RQ4**.

In the next chapter, this thesis presents the state of the art on technologies for supporting PA and the psychological, personal, and physical barriers addressed by the technologies.

4. STATE OF THE ART

This chapter presents relevant previous research from the literature on ubiquitous and affective computing and HCI. In particular, this chapter provides: (1) an analysis of technologies for promoting PA and their possible limitations in dealing with psychological barriers; (2) an identification of the studies using sound feedback to alter BP; (3) a summary of the studies that use technologies to support different adult populations by addressing their barriers or facilitators to perform PA; and (4) an identification of those studies involving technologies that use sound feedback or movement sonification for therapy and their potential use for altering BP.

4.1. Technologies for physical activity

In previous sections, this thesis reviewed various sound paradigms and technologies used to provide sensory information and alter BP. However, they fall short on addressing psychological barriers to PA introduced in Section 2.3 and discussed in Chapter 5 (e.g., confidence in one's body and perceived body appearance, sense of *lack of balance*, sense of feeling stuck, sense of absolute limits, etc.). This may be because most of these technologies are focused on exploring and evoking body illusions and not on facilitating PA.

This section provides a literature review of various studies on technologies (e.g., wearable devices) for PA and how they have explored novel ways to help people to engage in PA or have proposed prototypes to change sedentary behavior. Moreover, this section also provides a review of sound technologies to support PA that has shown encouraging results for some exercises or movements.

The aims of this literature review are to understand what exists and can be reused and what are the gaps in technologies designed to promote PA in physically inactive people. Recent research on interactive technology has explored how technology can be used to support PA in different ways, some of them combining movement tracking, goal setting, or feedback on PA [5]. However, the results of the literature review showed how technologies to support and promote PA focus little on working with psychological factors (barriers introduced in Section 2.3 and detailed in Chapter 5).

For this literature review, the current technologies for promoting PA are divided into those addressing psychological, physical, and personal factors (barriers/needs), and strategies to support PA (Facilitators). Once the papers were selected based on barriers and facilitators, the articles were analyzed, and several aspects to promote PA were identified in the analysis: strategies (e.g., goal setting-behavior, social contagion, competition, coaching, planning, self-monitoring on performance) and type of feedback (visual, music, or other sound feedback). It is worth's highlight the research works that promote PA focus more on social influence. A summary of the articles emerging from the literature review is provided in TABLE 4.1. The type of evaluation, the stakeholders for whom the technology was designed, its barriers and strategies are detailed for each article.

TABLE 4.1: RELEVANT PREVIOUS WORK ON PHYSICAL ACTIVITY TECHNOLOGIES.

			Barriers/Needs			**Strategies to support PA / Facilitators**
Authors	**Type of evaluation**	**Population (Age)**	**Personal**	**Physical**	**Psychological**	
(Phan et al., 2014) [69]	Evaluation study (n=123)	People with overweight or obesity (n/a)				Social contagion, competition
(Ren et al., 2018) [70]	Field study (n=20)	Co-workers (25 - 35 years old)				Social contagion, cooperative goals
(Paruthi et al., 2018) [71]	Semi-structured interview (n=16)	Office workers (25 – 35 and 35-45 years old)	X			Daily and goal adherence visualization
(Ming et al., 2017) [72]	Field study (n=21)	Adults (18-24, 25-34, 35 – 44, 45 – 54, 55 – 64 years old)	X			Daily and goal adherence visualization, self-monitoring
(Turchaninova et al., 2015) [73]	Field study (n=220)	People with overweight and obesity (n/a)				Social contagion, competition
(Mollee et al., 2017) [74]	Field study (n=90)	Young adults (18-30 years old)				Coaching system, goal-setting, self-monitoring
(Ciravegna et al., 2019) [75]	Field study (n= 250,000)	Physically inactive people (n/a)	X			Goal setting, self-monitoring, rewards

			Barriers/Needs			Strategies to support PA / Facilitators
Authors	**Type of evaluation**	**Population (Age)**	**Personal**	**Physical**	**Psychological**	
(Singh et al., 2014) [27]	Design study & Field study (n=8)	People with chronic pain (n/a)		X	X	Enjoyment, Motivation, Ability, Triggers, and relaxation/**sound** feedback
(Gupta et al., 2018b) [76]	Pilot study (n=10)	Osteoarthritis, Rheumatoid arthritis patients and physiotherapist (n/a)	X	X		Coaching system, self-monitoring
(Byrne et al., 2018) [77]	Pilot study (n=7)	Sedentary individuals with type 2 diabetes mellitus - T2DM (n/a)		X	X	Daily and goal adherence visualization, coaching system
(Brombacher et al., 2019) [78]	3 design interventions - Design framework (n=61)	Office workers (n/a)	X		X	Social contagion
(Khot et al., 2015) [79]	Field study (n= 6)	adults with low and moderate, and high PA level. (n/a)	X			Motivation, Social contagion, self-monitoring, **Fluidic visualization and an appetizing drink**
(Dogangün et al., 2017) [80]	Field study (n=8)	Adults (20-34 years old)	X			Daily and goal adherence visualization
(Nakanishi & Kitamura, 2016) [81]	Evaluation study (n=48)	University students (18-22 years old)				Competitions, self-monitoring
(Kanaoka & Mutlu, 2015) [82]	Formative (n=8) & Evaluation study (n=24)	1.- Adults (18-25 years old) 2.- Adults low and moderate PA level (18-48 years old)				Social interaction and engagement

			Barriers/Needs			Strategies to support PA / Facilitators
Authors	**Type of evaluation**	**Population (Age)**	**Personal**	**Physical**	**Psychological**	
(Ketcheson et al., 2015) [83]	Evaluation study (n=20)	University students (11 PA) (age= 18-26 years old)				Enjoyment, Motivation, Ability, Triggers, and relaxation (**exergame**)
(Mason et al., 2019) [84]	Semi-structured interview (n=8) & survey (n=44)	52 Wheelchair adults (20-61 years old)		X		Enjoyment, Motivation / (**music**-based adaptative **exergame**)
(Altmeyer et al., 2018) [85]	Evaluation study (n=9)	Older adults (57-87 years old)		X		Social contagion, competition, comparison, cooperative, reward, self-monitoring.
(Araújo et al., 2015) [86]	Evaluation study (n=20)	Adults (19-28 years old)				Social contagion
(Marcu et al., 2018) [87]	Codesign (n=6) & Evaluation study (n=4)	Cancer survivors (age avg= 35)			X	Goal setting, reward, self-monitoring
(Kappen et al., 2017) [88]	Survey study (n=192)	Adults (18-65 years old)	X		X	Goal setting, self-monitoring
(Randriambelonoro et al., 2015) [89]	Evaluation study (n=18)	Obese and diabetic population (36-73 years old)	X			Self-monitoring
(Tajadura-Jiménez et al., 2019) [33]	Evaluation study 1 (n=30) & Evaluation study 2 (n=22)	Adults (19-30 & 18- 28 years old)			X	Changes in BP, **Sound feedback.**
(He & Agu, 2014) [90]	Evaluation study (n=8)	Sedentary adults (n/a)	X		X	Goal-setting, self-monitoring and recommendation
(Chatta et al. 2015) [91]	Evaluation study 1 & study 2 (n=14 & n=20)	Undergraduate students (n/a)				Enjoyment, Motivation / (**exergame**)

			Barriers/Needs			Strategies to support PA / Facilitators
Authors	**Type of evaluation**	**Population (Age)**	**Personal**	**Physical**	**Psychological**	
(Veazanchin & Laviola, 2015) [92]	Design & Evaluation study (n= 48)	University population (18-26 years old)				Competition (**exergame**)
(Shameli et al., 2017) [93]	Evaluation long-term study (n= 2,432)	Active and low activity people (avg age= 34 years old)				Competition, self-monitoring
(Zuckerman & Gal-Oz, 2014) [94]	Evaluation study 1 (n=40) & study 2 (n=59)	Adults (23-54 years old) and students (20.27 years old)			X	Goal setting, self-monitoring
(Ciman et al., 2016) [95]	Evaluation study (n=13)	Bachelor and master students (24-30 years old)				Motivation, Ability, Triggers, and relaxation, Competitions
(Alqahtani et al., 2020) [96]	Evaluation long-term study (13)	Adults with low to moderate PA level (n/a)				Goal setting, self-monitoring
(Cherubini et al., 2020) [97]	Experimental design & interventions (n= 208)	University students (avg. age= 18 years old)	X		X	Goal setting, feedback (step counter)
(Almutari & Orji, 2021) [98]	Survey study (n= 217)	Saudi Adults (age= 18-35, 36-45, & >65)	X			n/a
(Mason et al., 2020) [99]	Player experience evaluation study (n=8)	Wheelchair adults (age= 18-44)		X		Enjoyment (positive experiences)
(Sun et al., 2020) [100]	Design & preliminary study (n=5)	Clinicians - cardiovascular diseases (age= 23-34 years old)	X			Motivation (messages), self-monitoring
(Yoo et al., 2020) [101]	Field study (n=11)	Sedentary workers (18-29, 30-49, & over 50)	X			Enjoyment, Motivation, Competition, self-monitoring

a. Most of the works provided visual feedback on their systems or applications, identifying in bold those with a different feedback.

b. Find in bold the work with exergames.

4.2. Psychological factors that facilitate or prevent PA

4.2.1. Goal setting behavior

The Goal setting behavior strategy utilizes challenges, objectives, or rewards for motivating and increasing adherence when performing physical activities [4], [5], [31], [72], [75], [96], [102]. For example, mobile apps support planning by prompting the user to make plans about when they will perform PA [102] or coaching [74], [77]. Likewise, a study showed that combining motion tracking, rewards, and feedback increases PA in physically active adults [31]. The subjects used a pedometer and received daily step goals; when participants reached their step goal, they received a message as a reward of their achievement. Results showed an increase/decrease in their performance according to the type of feedback or motivational messages [31]. These studies suggest that when devices (e.g., sensors or smartphones) are combined or accompanied by interactive apps with goal settings or rewarding feedback [2], these can be effective tools to provide information (e.g., amount of PA or intensity) and to encourage engagement and motivate PA.

Different research projects have explored goal setting to help in PA combining with gamification or receiving messages (see in bold the technology, facilitator, or barriers identified in the research works). For instance, [94] used “StepByStep”, that is, an accelerometer-based **smartphone application** to promote **walking** that uses the **goal-setting** mechanism and **gamification**. Two studies were conducted. The first study (n=40) was a quantitative study to evaluate “StepByStep”. The second study (n=55) compared three versions of “StepByStep” with a gamified version (**virtual rewards and social comparison**). This work proposes points as rewards for walking time and a leaderboard, which is ranking participants according to the points obtained. However, no differences were found between the different versions; participants considered the rewards meaningless by them, and they were more interested in walking time. The researchers suggest that in addition to comparing the elements of the game, it is also necessary to take into account the social context, according to the user's situation. So, it opens a point to investigate not only the social context but also those psychological aspects related to BP [103].

Another example is [90], that presents “On11”, a **smartphone application** that recommends personalized (through messages) short **walks** and that it was designed taking into account barriers such as **time (appropriate schedule), lack of resources, lack of**

the right equipment, weather and physical condition (fitness level, weight). "On 11" was evaluated in a user study (n=7) for two weeks. The results showed that participants commonly did not want to be annoyed by being told they were "being inactive" too frequently, even if they were aware that this was indeed true, which suggested that research should be done into better ways of prompting users about their sedentary patterns without annoying them in future iterations.

In [87], a **smartphone-based PA application** called "Bounce" for cancer survivors was described. "Bounce" was designed based on theory-based strategies including **goal setting**, **rewards**, and **self-monitoring**. A study to evaluate the validity and feasibility of "Bounce" was performed with 4 breast cancer survivors. Participants were interviewed before and after using their smartphones and the mobile application. The interview focused on their experiences with treatment, their barriers to PA, and their wellness goals. Cancer survivors perceive several **barriers to PA: fear of pain, fatigue, actual pain from attempting to exercise, and limited access to specific advice for breast cancer survivors pertaining to exercise**. The results highlight the importance of quality (i.e., adaptable intensity, variety, and exercise duration to support the goals and needs of each user) in a PA intervention. One of the most effective features of the Bounce intervention was providing a well-balanced workout program, and participants also reported the adaptation of exercise intensity, variety, and duration to help the individual needs and objectives of the users.

Lastly, [88], focused on a systematic review of PA and Self-Determination Theory. Kappen found that previous research work did not focus on addressing PA or motivational affordances. Therefore, they performed an online survey (n=150) to explore motivational affordances and the preferences in technology for PA. The survey results showed different negative attributes according to age: people between 18-29 did not consider important step counters or social affordances, but goals and challenges, while people of 65 and more found being aware of time and challenges (competitions) as unnecessary or evoking stress. On the other hand, participants find positive affordances to facilitate goals and continuance of PA in elements like a badge (game elements), in goals, and in feedback of progression. Therefore, this research work highlights the importance of understanding how to use psychological factors, such as motivational affordance, to promote or increase PA.

4.2.2. Providing feedback on performances

Through smartphone apps and sensors, PA can be measured to provide feedback on performance and encourage PA in users [1], [2], [72]. For example, "activPAL" uses an accelerometer to measure the walking cadence and steps, and identify if the subjects are sitting, standing, or walking [31]. Its aim was to validate the feasibility and accuracy of the movement to estimate time in the different intensity categories of PA (sedentary, light, and moderate-to-vigorous PA). In PA, technologies are effective for providing feedback on exercise, but research work is needed to provide support or help to address psychological factors, such as enhancing perceived flexibility or agility.

In the research work [77], an **adaptive coaching mobile application** for sedentary individuals with type 2 diabetes mellitus was used. The application provides **daily and weekly reminders** through messages and prompts users to complete a small session of walking exercise; for that, the application combines **goal setting** and **self-efficacy** theories of behavioral change. A study was conducted with 7 participants to examine the feasibility of both theories in the coach application and to get PA adherence by helping to overcome the **weather barrier**. The results showed that it is possible to have a high adherence and increased levels of PA in sedentary type 2 diabetics.

In [97] a **mobile application** was used with **tangible rewards and to send motivational messages** to users. This research work considered self-determination theory [104] and followed three basic psychological needs: **autonomy (self-congruency and integration), competence (effective and dominance), and relatedness (social context)**. The study was conducted with 220 participants (208 for analysis). Participants were randomly assigned to the control group or to three intervention groups with different kinds of messages and rewards. However, results showed that tangible rewards do not help to build long-term healthy habits. The main result of this study was that, even though PA did not change considerably, the intrinsic motivation of the subjects did change as a result of the experimental interventions. The **high frequency feedback of messages could also be perceived negatively** by users and discourage them in their objectives to establish a healthy exercise habit. In relation to PA, while techniques of behavioral change were effective for working on psychological factors, e.g., autonomy, competence, and social context, they didn't provide real-time feedback support during the exercise of PA that combined with addressing psychological needs could help to increase adherence to PA or create healthy habits.

The technologies above mentioned (Section 4.2.1 goal-setting and Section 4.2.2 provide feedback) focused on ways of tracking activities (e.g., running) and understanding the best strategies to present data to long-term trackers (e.g., hourly or by a goal) to increase awareness of PA and engage individuals with an active lifestyle [5] or to help them recover from motor issues [105]. However, it is still a challenge to achieve long-term adherence to PA in sedentary or inactive people [106]: while by using these technologies users may become more aware of their problems, they are often incapable of changing behavior by themselves, as highlighted in [107]. Works focusing on psychological needs or barriers that prevent PA [6], [30], [41], [108] have identified significant correlations between PA and barriers related to self-esteem, motivation, BP (e.g., proprioception), or affective states, among others. Although some of these technologies are well-implemented, whether they can support the psychological needs of people with low levels of PA has not been explored. However, this body of work emphasizes the importance of combining technology and their strategies to enhance the PA through providing feedback on performance or goal settings.

4.2.3. Social influence

The focus of this thesis is to increase PA considering psychological barriers. The literature review shows that there is a lot of work to increase PA based on social aspects. For example, through social contagion [70], [73], [78], [82], [85], [86], [94], [109], or through competition strategies [81], [92], [93], [95], [101]. There are other social conditions like influences based on location. For instance, the work with [98] investigates the Health Belief Model (HBM) and the Social Influence for PA collectivistic culture, i.e., Saudi Arabia, a culture group of which little is known. HBM allows them to understand people's reasons to make decisions to be healthy or prevent diseases and it is used in health interventions design. A long-term study based on a survey with 217 participants was conducted, which considered the influence in PA of the HBM factors: Perceived susceptibility, Perceived severity, Perceived benefit, Perceived barrier, and Self-efficacy in addition to the Social Influence factor. For the aim of this thesis, it is highlighted the findings related to perceived barriers. Findings show more barriers in females than males; barriers are linked to **social and cultural factors, with females** being more limited than male, for example in **dressing and conduct code**, and with **fewer** and **more expensive gyms** for females.

It is worth mentioning that the social networks are very studied in relation to PA, as in [69] where all users enrolled in an online social network application, allowing them to "friend" and communicate with each other. [73] propose "IBurnCalorie" (see FIGURE 4.1), a mobile application with visual feedback through an avatar that represents the activity of the user; when one user starts to follow other users, this user can begin tracking the other user's activity in real-time (e.g., number of steps/calories). To evaluate "IBurnCalorie", 220 subjects were part of a study, and 18 were virtual connections. "IBurnCalorie" was designed for overweight and obese users with the aim of identifying how to best match people to facilitate motivational connections with regard to PA. This research work concluded that "IBurnCalorie" made a drag effect among a small number of users during the time period of our data collection. These results showed the importance of social influence during PA but also showed a small group with low persistence, who were not motivated when using the app. This finding opens opportunities for future research with the aim of identifying factors (e.g., social as well as psychological) that motivate or prevent PA.

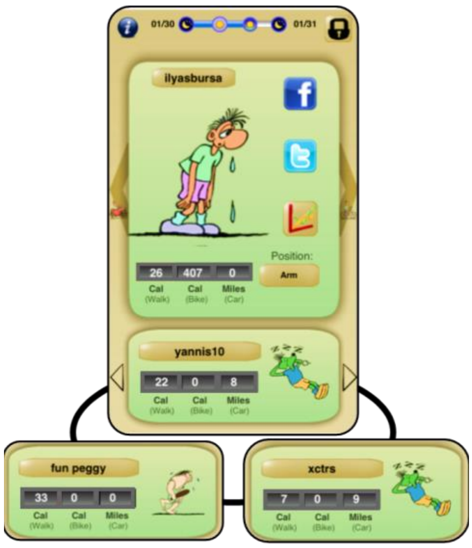


FIGURE 4.1: IBURNCALORIE APP OF [73].

Other works focus on exercising at the workplace [70]. [70] was based on a peer-based cooperative fitness tracking strategy for fitness promotion in the workplace. **Workers need or want to be more active, but spend most of their time in the office**. A field study was performed with co-workers to explore the influence in PA of adopting a cooperative fitness tracking strategy between co-workers. In the study (n=20) subjects were part of a 1-week intervention that involved recording **daily steps, collective goal setting, and data sharing.** For that, they used a fitness tracker named Mi-band to collect fitness data and implement the strategy, and they were interviewed before and after the intervention. The study showed several challenges for implementing the strategy set-up; these challenges are related to managing pairing before establishing cooperative fitness monitoring between co-workers, for example, through analyzing their routine overlap and proximity at work. Findings show that choosing positive role models can have a positive influence in PA-related health behavior. These technologies provide self-monitoring of PA and support through goal setting with a cooperative strategy, but they do not offer psychological support and do not give feedback in real-time for PA.

Additionally, in [78], a study was conducted with "Stimulight", a system that visualizes individual/colleague PA in the **social** context and if a user had been active or not. The application is connected to a Fitbit charge. This research work focused on 3 design interventions with 61 office workers to find out the initial reactions and users' behavior towards the system. The findings showed that the social interventions were more motivating than individual intervention, but highlighted the importance of also showing individual feedback, because if feedback was only given on a social level, the user's needs might have been limited. These technologies highlight the need for social support but also the importance of individual feedback. Overall, this work and previous works mentioned in this section do not provide support for psychological barriers or needs during the PA, [78] provide only the number of steps as feedback.

4.3. Physical and personal factors that prevent PA

In the literature review of this thesis physical factors that affect PA were also found [27], [77], [79], [84], [99]. For example, the work of [76] focuses on Osteoarthritis and Rheumatoid arthritis patients, a condition that **limits mobility by joint inflammation and functional independence**. They designed a web application for physiotherapists who coached the patients, and a Fitbit device for patients, and conducted a study that lasted 4 weeks. After the study, patients were interviewed and reported their interactions with the application and the conversations with the therapist using a calendar visualization. The results showed that the patient feels guilty when goals are not achieved, and arthritis patients may have different levels of symptoms that limit their mobility. In

PA when clinical patients are the target group, the need to address psychological barriers is even more prominent than in the healthy population; for example, this is the case for feelings of guilt or disappointment, which can be originated from sensations related to own's body, that is when there is a decrease in mobility and this inhibits the ability to accomplish the objectives.

Another example is [99], which describes a "Dash Lane" music-based adaptive exergame for people with **mobility impairment,** in which users practice upper body movements integrated into "Dash Lane". A study was conducted with 8 wheelchair users with the aim of understanding participant perspectives on engagement. The general results display the play's potential to break up periods of sedentary behavior during the day. Although this exergame seems to provide a playful interaction and real-time feedback during PA for physical barriers, it does not provide support for psychological barriers related to PA.

In the literature review of this thesis were also found personal factors that affect PA, e.g., routine [78] or lack of time [71], [88]–[90], [97], [100]. For instance, [80] present "DayActivizer", a mobile application (FIGURE 4.2) that gathers PA data from the user with the aim of creating **individual recommendations** for PA. The recommendations are based on developed strategies according to the characteristics of each user, for example, most frequent activities, similar sports activities, favored activities by age, or activities providing good feelings. To test the strategies implemented in "DayActivizer" a study was run with 8 participants that identified their daily routines for 4 weeks. Results show that a user model could be constructed with success from user-recorded data, but the lack of contextual information and information about users' preferences and dislikes led to some unacceptable recommendations.

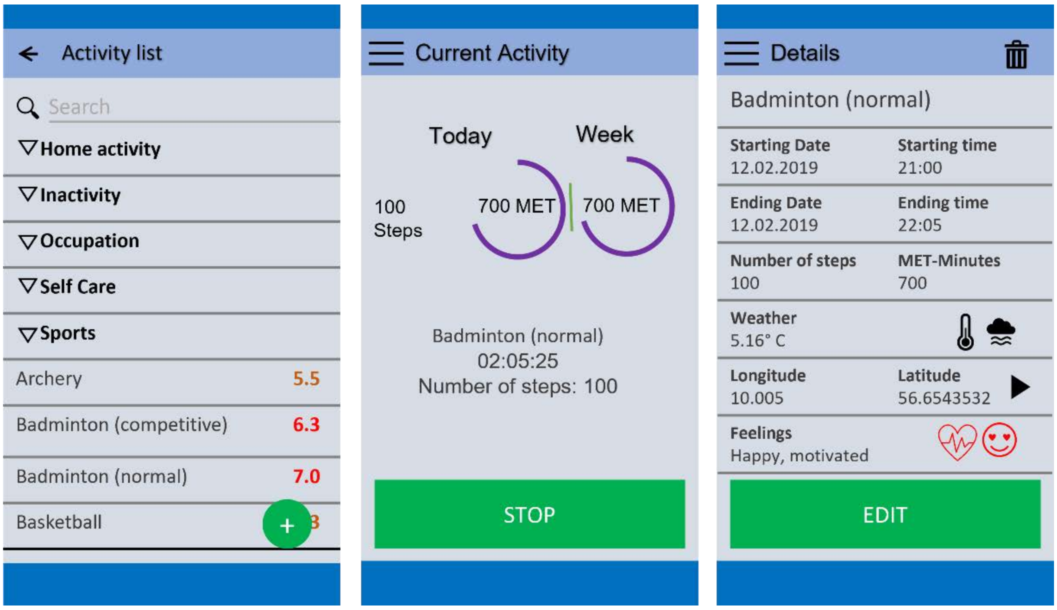


FIGURE 4.2: SCREENSHOT OF THE SELECTABLE ACTIVITY LIST OF DAYACTIVIZER [80].

While the previous study focused on the general population, [89], [91] focus on helping people with overweight. In particular, the work of [89] focuses on overweight and diabetics populations. They conducted an in-situ study where participants used a Fitbit One tracker fitness application. Participants were interviewed at the start and the end of the study to acquire vivid pictures of their daily life and evidence on whether, why, and how this technology impacted patients by motivating PA and changing their lifestyles. The research work observed acceptance of the technology, with participants reporting **changes in their lifestyles and sharing their experiences using Fitbit in their social environmen**t. This work takes into account changes in behavior; however, this work does not provide real-time feedback, and research is needed to understand the psychological needs of a specific population, i.e., overweight people and diabetics.

Many of these studies have been looking at the self-monitoring of PA. They have explored how wearable devices can encourage engagement in PA, using commercial devices such as Fitbit [72] or smartphones [5], which often integrate sensors of the physiological activity or PA e.g., heart rate monitor, step tracker, accelerometers, or pressure sensors. Sensor inputs are computed and accompanied by interactive apps aiming to help people achieve their PA goals through awards, challenges, or messages [2]. For example, a smartphone app that reminds users to move to avoid sedentarism [5]. Although these works show the first steps or applications to make recommendations for general populations, they show challenges in understanding the needs or barriers in the context of use or for specific populations, and hence challenges for the successful implementation of these technologies in the real world.

4.4. Movement sonification to affect body perception.

In the previous section (Section 4.1, 4.2, and 4.3), this thesis reviewed the technologies to support PA. The literature review highlighted the lack of technologies to address psychological barriers, including psychological barriers related to BP. While these technologies have been designed frequently with the aim of supporting PA through strategies, i.e., goal-setting behavior, providing feedback on performance, and social context; they do not address the psychological barriers to PA, with the exception of motivation. In addition, the literature review performed in this thesis found that most of the articles obtained reported the use of feedback through the visual modality; only three articles were found in the literature review that provide some kind of sound feedback (see Section 4.4.1). This may be because most of the technologies are designed with the aim of measuring and increasing performance or are focusing more on motivation and do not provide real-time feedback nor address barriers of PA, specifically in physically inactive people.

On the other hand, Section 2.2 introduced the psychological factors involved in PA related to BP [6], and the potential of neuroscientific research that uses sensory feedback to induce changes in BP [14], [32]. Sound, and in particular the altering of the sounds that our body naturally produces when moving and interacting with surfaces, has been proven to be an efficient sensory channel to induce such changes in BP [15], [17], [59].

This thesis proposed the used of interactive sonification, this approach is defined as "the use of sound within a tightly closed human–computer interface where the auditory signal provides information about data under analysis, or about the interaction itself, which is useful for refining the activity" [18]. This thesis introduces interactive movement sonification, that it will be interpreted as the use of a wearable device to provide auditory feedback about the interaction itself to help refine basic movements [19]. To be more specific, it will be referred to as movement sonification.

Therefore, in the next section, this thesis reviews the technologies with real-time sound feedback that provide changes in behavior and are used to support sports, dance, and therapies.

4.4.1. Technology with sound feedback to support PA

As mentioned above, this thesis found a gap in the use of sound feedback to support PA. Three articles were found in the literature review that reported the use of sound feedback [27], [33], [99]: two of them show a potential to alter BP, and provoke changes in behavior [27], [33]; the third study is “Dash Lane” a music-based adaptive exergame that supports physical barriers (see Section 4.3).

Go-With-The-Flow [27] is a wearable device that provides **sound feedback** for people with chronic pain (CP) during PA in daily life. Several studies were performed to design and evaluate Going-With-The-Flow. The first one, a design study, with 12 physiotherapists and 84 participants with CP, to understand how they would maintain and enhance PA in their **daily routine** and what factors discouraged them to do so. The findings reveal psychological barriers, such as **fear of damage or increasing pain.** Based on this understanding of behavior of people with CP a series of design considerations were obtained. The second study was a field study with 8 CP participants (26-30 years old) which aimed to evaluate the Go-With-The-Flow prototype that provided participants with sound feedback on their low back position and movement. In the interviews, all subjects considered the auditory feedback to be useful and motivating because of the feedback on their performance, effort, and perceived range of movement (e.g., reach maximum stretch).

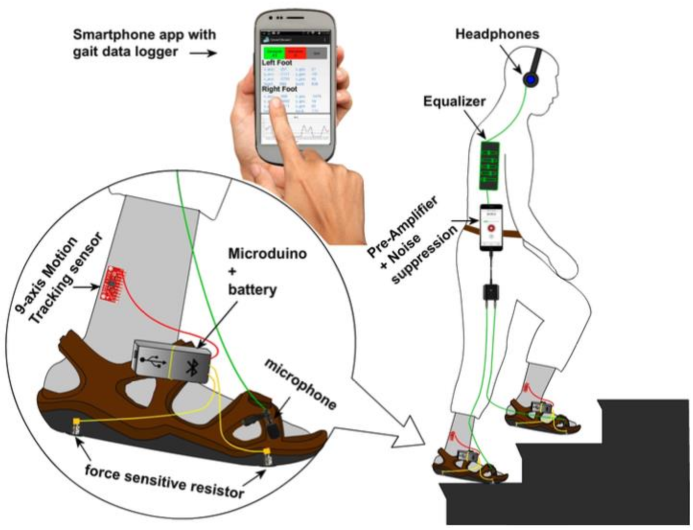


FIGURE 4.3: ILLUSTRATION OF THE SET-UP IN [33].

[33] used a smartphone app and connected it to a Smart shoes prototype that provided **sound feedback** during **walking (see** FIGURE 4.3**)**. Smart shoes are a pair of strapped sandals with two force-sensitive resistors (FSRs) and Motion Tracking devices (MEMS)

in each foot that monitor movement, as well as a sound system that modifies the sound of one's footsteps in real-time. Two evaluation studies were performed to explore the effect of altered sound feedback on BP, body and gender feelings, and gait. The barriers mentioned in the study related to BP were **self-efficacy and self-confidence**, **social exposure/pressure, and lack of control over the activity**. In the first evaluation study, participants (n=30) used a gym step while listening to their altered footstep sounds in three different conditions: either they listened to their natural footstep sounds like a "control" condition, or their listened to High- or Low-Frequency versions of those sounds. In the second evaluation study (n=22) participants were exposed to the same sound conditions as in study 1 but while climbing stairs. The results found participants felt quicker, lighter, feminine, and more in control with High-Frequency than Low-Frequency versions of the sounds. Moreover, the Low-Frequency sound made the participants feel the exercise was more difficult in relation to effort, as compared to the High-Frequency sound, which made the exercise easier and less tiring. The study showed the potential of providing bodily sound feedback at the time of exercise to facilitate PA.

4.4.2. Movement sonification to facilitate sport, dance, and motor therapy

As mentioned in the previous chapter (Chapter 2), [59] showed that altering the spatial location of the sounds produced when tapping a hand on a surface can result in perceiving and acting as if one's arm was longer. The alteration of one's perceived body may in turn have an effect on motor behavior and PA capabilities. For instance, recent studies showed that altering the natural footstep sounds produced by a person walking can make the person feel slimmer and lighter and adapt their walking behavior; [17], [33], FIGURE 4.4.

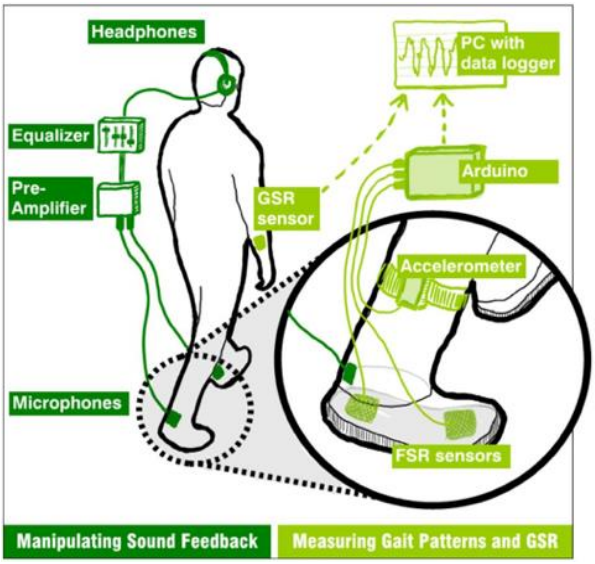


FIGURE 4.4: OVERVIEW OF THE EXPERIMENTAL SETUP, MANIPULATING SOUND FEEDBACK, GAIT SENSOR [17] .

While these works (Chapter 2, Section 2.2) focused on altering the natural sounds produced by the body as a source of body alteration, an alternative approach to change BP could be employing movement sonification.

Movement sonification has been used successfully for motivating, informing, and guiding people on their movement (start/end, or to accompanying the movement), and specifically, it has been used effectively in sports persons or patients on their movements during PA, [21]–[23], dance [37], [110], [111], and motor rehabilitation [25]–[27], also motor rehabilitation of upper or lower limbs [25]–[27], interventions [112] and in reconnecting with functional activity [108].

For motor rehabilitation, the goal of guiding or informing movement is emphasized.. For example, a study that focused on children with autism who need to improve their motor skills, investigated the use of interactive sonification of side arm movements to impact these children's motor skills [112]. The results of this study showed that movement sonification with discrete sound structures makes children with autism more aware of their movements, and it helps them to perform their movements correctly. These works use sounds to provide the users with information about their body movement, such as when the beginning and the end of the movement occur, or to inform about their movement trajectory. Here, this thesis investigates how sonifications can be used or designed to address the barriers related to BP.

Various works have investigated the characteristics of sounds to enhance its effect on movement. For example, one of the studies is [26], in which the effects of movement sonification for stroke rehabilitation were investigated. Results showed that the use of sound characterized by discrete intervals (or discrete sound structures) and timbre from instrumental sound improved the control of arm positions related to proprioception. This study showed the potential to enhance the perception of location of a limb in space during the movement. Thus, this study showed the potential of research on proprioception, and in particular about how to design sonifications with the aim of supporting proprioception and the sense of movement control.

Further, [22] focused on people who struggle to perform PA. They investigated how stable sounds (i.e., where the sonification is musically resolved) and unstable sounds (i.e., musically unresolved) accompanying squat movement would impact on the perception of the movement. Their results showed that participants felt a stronger sense of achievement in the completeness of the movement with the stable sound and were more motivated to do more repetitions with the unstable sound. Music can help with mood and activation [113]–[115], but it does not work on altering specific BPs or guiding movement, such as flexibility and control of movement. In [112], musical notes or sounds based on music allowed for exploring new ways to design sonifications. In this study, the authors explored the understanding of movement sonification of children with autism during lateral, cross-lateral, and push movements; and its potential in motor therapeutic interventions, FIGURE 4.5. This work ran two studies with discrete (drums, or musical scale) and continuous (wind, water) sounds. This work showed the use of metaphors (e.g., wind), which may be used to facilitate the relationship between the qualities of movement and sound. Similarly, the use of metaphors [116], [117] in this thesis may show potential to evoke metaphor-related changes in the perception of certain body movement qualities (e.g., fluidity or flexibility).

FIGURE 4.5: A PARTICIPANT PERFORMING LATERAL MOVEMENT WHILE LISTENING TO THE “DISCRETE SOUNDS WITH TRAJECTORY” IN [112].

Such studies are just some of the critical examples of how, if carefully designed, movement sonification has indeed the power to enhance body and movement awareness, self-efficacy, and motivation towards PA [118]. The common factor in these studies is the use of specific sound characteristics as sensory information on body movement to lead or help the movement.

4.4.3. Movement sonification for altering BP during PA

There are studies with movement sonification that demonstrated the support to PA through sensory information [25], [27], [119], [120], such as by *enhancing proprioception* [37] and the *sense of control of movements* [121]. For example, a previous project [37], used a wearable device integrating two Force Sensitive Resistors and goniometers and real-time audio, to support training and dance teaching, specifically the jumps “*Sauté*” and “*Italien Changement*”. The angles of the joints, the distribution of the weight on the feet, and the jump energy are indicated through sonification and were clearly recognized, as well as helped students to correctly execute the movements, FIGURE 4.6.

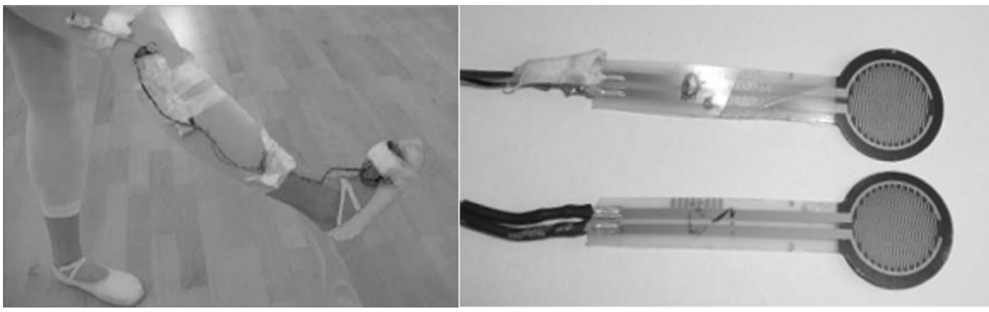


FIGURE 4.6: POSITION OF THE SENSOR FIXED ON THE LEG OF A DANCER AND FSR SENSORS, GONIOMETER IN THE KNEE, AND A SENSOR BOARD ON THE FOOT [37].

Also, some works talk about the relation between sound and *body appearance*. Some studies talk about how it is possible to recognize appearance from sounds [122], while other studies focused on how to enhance perceived body appearance through sound [17], [123]. For example, Li et al [122] explore the acoustical properties of walking sounds (high and low frequency) on the gender perception of walkers in casual listeners. The results of the study showed that listeners attributed the sound of footsteps with a dominant high frequency to females, while they attributed the sounds with a dominant low frequency to males.

In terms of the relation between sound and perceived body capabilities, some works have shown the potential of sound feedback to increase *the perceived cardiorespiratory resistance* [21], [124], [125]. In [125], it was created a model for a music-based system providing feedback on the physiological processes (e.g., cardiovascular or respiratory). The model gathers ideas and theories related to the human sensorimotor interaction with music with the aim of reinforcing the use of music-based feedback for sport and motor rehabilitation. Their research found that music-based feedback on physiological functions (e.g., heart rate) can teach subjects to control these functions and help to manage their anxiety. Moreover, there are other works that showed that movement sonification can be used to increase the perception of muscle strength and resistance [117]. [117] used a collection of sounds created by actions on domestic context objects, and asked participants to describe the sound; for example, the sound of crushing a metallic can, it was described as "discontinuous", "metal can", "to crush". This description shows the potential for such sounds to increase the perception of strength or resistance, because the results also show how the identification of domestic sounds has a direct effect in the gestural strategies, as participants tend to replicate the real action while describing the sound, as applying force to crush metal.

Following this, there are some research works showing the potential of using movement sonification to *enhance perception of speed or agility* [17], [40], [126], [127]. For example, in this work [126] used interactive sonification to lead children's spontaneous gross movements. In this investigation, researchers created and tested three different sound models based on filters of noise. The first sound structure produced a soft, wind-like sound; the second produced a rougher sound; and the third produced a broken, snapping sound. A first study with 11 children recorded them while moving and producing a sound. A second study in which the movements and sounds created by the children are rated in a scale of different movement qualities by adults (5 females). The findings communicate children's movement and sound as more fluid and movement with more energy and impulsiveness.

Similarly, to *enhance perceived flexibility*, a study with a wearable device for people with chronic pain showed that the use of discrete but varying tone-based sonification could be effective, motivating, informative, and attractive to PA; simple vs complex sound structures with information on body position were more effective in improving users' body awareness, which in turn helped to address their anxiety during general PA [41].

Lastly, it is possible to find examples of works aimed to give or increase the *perception of movement progress/achievement* [27], [41], [120], [128], [129]. The study by [120] uses metaphorical sounds to indicate the exit of the range of motion, positive (get the right sound only with the right movement) and negative (get stuck and loop, or slow down and lose their pitch) movement patterns.

Sonification is not new in research about PA. Indeed, movement sonification has been shown to facilitate body movement, but also it has shown the potential to change body sensations during PA. This bodywork supports the use of movement sonification as a potential approach to promote PA through altering body and movement perception.

4.5. Conclusion

The abovementioned technologies (Section 4.4) have in common the use of sound as auditory signals on body movement to lead or help the movement. Indeed, the above-described studies demonstrate that sound can affect the perception of the movement. While there is much less work focused on sound as a source of sensory alteration of one's own BP, recent works have also shown that by manipulating the sounds produced by own body movements it is possible to alter BP and in turn the related emotional state and motor behavior.

On the other hand, the above-mentioned technologies (Section 4.1, 4.2, and 4.3) mostly focus on providing quantitative feedback on PA (e.g., amount of PA, or goals achieved); when this information is presented to the users, they may become aware of their low level of PA. For instance, in [22] the feedback received was in response to the daily report or during a weekly face-to-face meeting; even when the feedback seems to be successful in getting step goals and increasing PA, PA decreases when feedback is removed. Physically inactive people that are aware of their activity levels may still feel incapable of changing behavior by themselves [1], [7]. These technologies do not focus on helping physically inactive people to overcome their psychological barriers and physical limitations, nor focus on motivating progress, movement endurance or creating personally rewarding experiences. Consequently, people with low PA levels find it challenging to achieve long-term adherence, as highlighted in [7], [106]. To address this gap, works that, by focusing on psychological needs or barriers that prevent PA adherence, highlighted a relation between PA and BP (e.g., capability, strength) were considered [6].

This work propose to act on the psychological barriers related to BP and affective states in inactive people as a way to change behavior and promote adherence to PA in this group. This thesis builds on prior studies using real-time audio feedback on movement to help the movement or to alter BP. Moreover, this thesis proposes to investigate how metaphorical and non-metaphorical sounds, and in particular their characteristics, lead to changes in BP, impact on movement and facilitate PA, while also studying how effects hold over time, with more exposures, and differ between active and inactive populations and context of use.

4.6. Chapter Summary

TABLE 4.1 shows a summary of the work presented in this chapter. The type of technology used, the end-users for whom the technology was designed, its purpose and the type of evaluation are detailed for each article. As it can be seen in TABLE 4.1, there is much work on the development of technologies to support people during PA, but little has been explored to support people with low levels of PA based on their psychological barriers to PA or have indirectly targeted them. On the other hand, there are works using technology and movement sonification to support PA through sensory information for several kinds of people, but they have not explored the use of a movement sonification approach to support PA through alterations on their BP. Finally, interactive sonification has been shown to be effective in supporting user interaction with sound by providing real-time feedback on their movement; however, most studies have only focused on guiding or leading the performance of the different populations (young adults, wheelchair adults, or clinicians) or proposing potential applications (coaching, therapies, exergames).

5. PROPOSED SOLUTIONS

In the previous chapter, it was mentioned that the Design Science Research Methodology contains three fields, i.e., Environment, Research Design, and Knowledge Base. To allow the interaction between the three fields of methodology there are three cycles: Relevance Cycle, Rigor Cycle, and Design Cycle. In this context, the first step of the research was carried out and depended on the Relevance and Rigor Cycles to obtain the information from the Environment and Knowledge Base, which led to the problem identification and formulation of the research questions, and objectives. Following this idea, the information obtained allows iterating between two phases through the Design Cycle: the design, and evaluation of the solutions. In this chapter, the focus is on the Design phase and on presenting the details about the solutions, how it was designed and created; as well as on the Evaluation phase, explaining how the evaluation of the solutions started. A diagram of the Research Methodology in context with this thesis can be seen above in FIGURE 3.1.

As the previous chapter introduces, the consideration of the Knowledge Base allowed proposing a new method to address the psychological barriers related to PA, through altering BP while enhancing people's feelings (e.g., flexibility, agility, and capability to do PA) of their own body. The proposed solutions are built on the combination of two approaches: a consideration of the **bottom-up multisensory mechanisms related to BP** and **interactive movement sonification** (see Chapter 2 for background). The method consists of mapping the movements created by a person's body into metaphorical or non-metaphorical sounds to evoke changes in the person's mental representation of the body or its movement. Likewise, the first phase of the design cycle led to the design of the prototypes **SoniShoes** and **SoniBand,** two wearable devices that allowed the implementation and future evaluation of the proposed method. Based on the first specific objective (**SO1**) and research question (**RQ1**) (*"What are the psychological barriers to physical activity related to body perception and what strategies can be used to overcome them by physically inactive adults?"*) the SoniShoes and SoniBand were developed and adapted to integrate a movement-sound palette suitable to evoke changes in BP, and to allow an examination of the effects in the body movement of the person. These prototypes are built on prior work with the so-called MagicShoes prototype that allows to change the sounds people produce while performing walking [17], see more details in Section 5.2.

5.1. Development of a taxonomy to propose movement-sound palettes

In order to design the movement-sound palette to change BP, and in turn movement behavior and emotional state, during PA it was necessary to find specific evidence in the Knowledge Base which is related to barriers related to BP and behavior that prevent PA (**RQ1**). This is not straightforward, as physically inactive adults could have different needs or barriers to PA and these are usually very broad. Because of that, it is often helpful to put the obtained knowledge onto a clearer and more organized method i.e., a taxonomy. Analyzing the contributions for designing technology to change PA behavior, the next phase was to adapt the steps to develop and test a taxonomy by [130], [131]. Both authors describe the steps to develop a taxonomy related to PA (FIGURE 5.1). The identified steps were the following: **1. Identification** of the source in this case related to PA, for instance, a list of techniques or tools; **2. Extraction and clustering of attributes,** new or existing categories of the selected lists through an iterative identification considering opinion expert, for example with pilot study; **3. Definition of instructions or considerations** through a manual on how to add any categories to the taxonomy.

Considering the scope of this thesis, the process of developing a taxonomy was adapted by [130], [131] focusing on the most relevant barriers related to BP. (1) **Identification**: identifying the barriers to PA related to BP[2]. (2) **Extraction and clustering of attributes:** filtering or clustering the identified barriers involving experts in the area to discuss identified barriers or to identify additional barriers. (3) **Definition of instructions:** defining the features or dimensions of where to act accordingly. An additional step was added that allows the transition to the evaluation phase searching. (4) **Strategies:** proposing strategies and movement-sound mappings that could help to overcome the barriers to PA of physically inactive adults.

[2] As my Ph.D. thesis was developed in the framework of a bigger research project www.magicshoes.es Step 1 was carried out by other team members, and my work initiated in step 2.

FIGURE 5.1: THE THREE STEPS FOR DEVELOPING A TAXONOMY AND THE LAST STEP FOR STRATEGIES OF THE MOVEMENT-SOUND PALETTE PROPOSED IN THIS THESIS, INSPIRED BY [130], [131].

5.1.1. Barriers' identification related to body perception

For the identification of the barriers that prevent PA the research team decided to combine three techniques or sources of information: literature review, surveys, and a focus group workshop.

5.1.1.1. Literature review

The first source of information was the literature review by the team [6] on the needs/barriers of PA to study which variables were taken into account or ignored in the design of technology to encourage PA. They [6] conducted both a psychology and computing literature review. The psychological review aimed to know which variables are affecting PA; the computing review aimed to understand which variables related to PA are addressed in the technology design for PA. The search was organized in three levels: physical, personal, and psychological variables; [6] focused especially on the psychological variables (e.g., self-confidence or self-esteem). The results showed 38 variables, of which 21 were psychological variables, acting as barriers or facilitators to PA; whether a variable is considered to be a barrier or a facilitator, depends on the point of view of the people; for instance, according to their body capabilities, people may consider something a challenge that motivates them to perform PA (i.e., a facilitator) or a barrier as they feel incapable to perform PA. From the full set of barriers, the most important variables for the aim were chosen by considering those variables which could potentially be modified through the designed technology. They include 9 Psychological variables and one Physical variable. These are the following: Fear; Discipline, initiative willpower, and commitment; Self-efficacy; Emotional/ psychological state; Self-confidence/self-esteem; Challenge difficulty; Awareness; and Energy level (see TABLE 5.1).

5.1.1.2. Survey

The second source is the information about the physically inactive population that the research team extracted from surveys [6], [46]. The first survey employed is The International Fitness Scale (IFiS), which assesses adults' self-perceptions of their physical fitness, defined as the self-perceived ability to perform PA (e.g., flexibility). The IFIS has been validated in different populations including young [46] and older adults [45]. It consists of five-point Likert-type response items, ranging from 1 to 5 (very poor - very good), which correspond to four categories of physical fitness: (1) *Cardiorespiratory Endurance*, (2) *Muscular Strength*, (3) *Speed/Agility,* and (4) *Flexibility*, and to *General physical fitness*. In [45], the (older adult) participants performed different tests, each one according to the 4 categories except for general physical fitness which is a compilation of the 4 categories. In [45], *Cardiorespiratory Endurance* is explained as the capacity to perform the PA during a time period. *Muscular strength* is expressed as the adult's power to hold or lift their limbs during PA. *Flexibility* refers to the capacity to do stretching in one's upper or lower limbs. *Speed/Agility* can be expressed as the ability to change from one position/activity to another totally different considering the speed to do it. The second survey employed was the Barriers questionnaire for PA (BQPA), a second contribution from [6] work, which aimed to identify which barriers need attention during the design/development of interventions/technologies for PA. 63 items were created to reflect the PA variables obtained from the Literature Review From the full set of items, 14 important items were chosen for the aim by considering those variables which could potentially be modified through the designed technology (see TABLE 5.1. Survey: BQPA). Lastly, as part of [6] additional variables were collected through other questionnaires that Rick used to measure BQPA: Motivation (intrinsic to extrinsic) that is their personal interest or the reward if perform the PA; Autonomy (take their own decisions), Competence (feeling with the skill), and relatedness (interaction with other people); Self-esteem related to PA, feel that trust in yourself to perform PA; Subjective importance of corporality; Physical attractiveness; and Care of physical appearance, that is the importance of the body appearance.

5.1.1.3. Focus group

The third source of information comes from the focus group that the research team conducted with experts in HCI and technologies for PA. A professor of Interaction Design and Innovation at University College London (UCL), with 18 years of experience, she is pioneering the Disability Interaction framework, and she is interested in accessibility and assistive technology. A professor of clinical health psychology at UCL, with 46 years of experience, she is focused on understanding of pain; evolutionary perspectives on pain; behavioral expression of pain and its interpretation by clinicians. As moderators: Aneesha Singh is a researcher focused on digital health, multisensory feedback and wearable technology. Nadia Bianchi-Berthouze is a pioneered researcher focused on affective computing and interaction, interested in designing full-body technology and body sensory feedback and how can modulate BP and capabilities, and Ana Tajadura Jiménez is a researcher focused on multisensory BP, wearable technology, and technologies for self-care, she combines HCI and neuroscience research. The focus group allowed to identify other potential barriers to PA based on their expertise in the area. The experts commented on qualities of the movement (e.g., movement fluidity or flexibility) which are important to consider, and how the physically inactive people perceive themselves. A summary of the barriers to PA identified through these three sources of information is given below in TABLE 5.1.

TABLE 5.1: STEP 1 OF THE TAXONOMY: BARRIERS TO PA THAT RELATE TO BP IDENTIFIED IN THE LITERATURE REVIEW [6], SURVEY AND FOCUS GROUP WITH EXPERTS IN HCI.

Source	**Barriers/variable**	**Description**
Literature Review [6]	–Self-efficacy/self-confidence	There is a lack of self-confidence or trust in one's capabilities or skills in performing PA. Self-efficacy seems to depend on the current PA level. Dissatisfaction with one's body (body appearance).
	–Awareness	Being self-aware, i.e., of one's body or the activity to perform can make people feel that they are doing PA wrongly, due to poor self-monitoring.
	–Fear	The feeling of fear is more present in low active adults, fear that PA can hurt one's body, e.g., get worse in an illness or physically. Also, it is related to the environmental factor, e.g., living in an insecure place.
	– Discipline, initiative, willpower, and commitment –Energy level (physical variable) – Emotional/ psychological state	Low level of energy, tiredness, or low mood are examples of emotional or psychological states that have been found mostly in technology literature.
Survey: BQPA [6]	–Self-confidence/self-esteem	Related to body appearance. Related BQPA item: *"I feel uncomfortable with my body"*.
	–Knowledge	Related BQPA item: *"I don't know how to do some particular exercises (e.g. using gym machines, swimming technique)."*
	–Energy level (physical variable) – Initiative, willpower, and commitment –Emotional/psychological state -Health/weight benefits	There is a lack of energy, low emotional state, and/or less initiative to perform PA. The related BQPA items are: *"I'm usually tired"*; *"I feel very tired to exercise"*; *"I feel lazy to exercise"*; *"I'm under some kind of stress", "I'm not in the mood"*; *"I don't feel my body being better when I exercise"*
	–Awareness –Self-efficacy –Fitness status –Pain or body sensations	There is a lack of self-awareness, proprioception, and incapability to perform the PA: The related BQPA items are: *"I don't like feeling aware of my own body when doing exercise"; "I am not aware whether my body posture is proper when exercising"; "I don't feel capable"; "I'm not in shape"; "I feel pain when exercising"*
	–Challenge and difficulty	The sense that exercise is challenging or considered difficult defines how frustrated or motivated the adult feels to engage in the PA. Related BQPA item: *"I feel frustrated when trying to do exercise."*

Source	Barriers/variable	Description
External survey: reported in BQPA [6]	Motivation (intrinsic to extrinsic): Autonomy, Competence, and relatedness	Motivation is their personal interest or the reward if they perform PA; it is divided into: Autonomy (take their own decisions), Competence (feeling with the skill), and relatedness (interaction with other people).
	Self-esteem related to PA	Feel that trust in yourself to perform PA; related to body appearance.
	Subjective importance of corporality; Physical attractiveness; and Care of physical appearance	Related to the importance of body appearance.
Survey: IFiS [45], [46]	Cardiorespiratory endurance	Self-perceived level of cardiorespiratory endurance.
	Muscular strength	Self-perceived level of strength to hold or lift their limbs during PA.
	Speed/agility	Self-perceived level of speed/agility to change from one position to another.
	Flexibility	Self-perceived level of flexibility in one's limbs.
	General physical fitness	Self-perceived general physical fitness level.
Focus Group	Movement progress	Lack of sense of progress/achievement of the movement.
	Solidity	This is in a way the opposite of perceived fragility, or fluidity.
	Feeling Stuck	A sense of impossibility to initiate/continue the movement.
	Sense of lack of balance	It is related to poor control and coordination to maintain the position.
	Sense of limits	Lack of sense of absolute limits/measure against yourself.
	Perceived power	It is related to the low energy employed. That is the perception of effort employed in the movement.
	Anxiety and vulnerability	The sense of fear, fragility, not being elastic, fear of falls.
	Confidence in one's body	As in the literature review.
	Perceived body fluidity	Lack of perceived body fluidity when people perform a smooth and coordinated movement.
	Self-esteem	Self-esteem related to exercise, as in the survey.

The next step was to filter and cluster the identified barriers or needs from the three previous sources, as explained in the next section[3].

5.1.2. Barriers' filtering & clustering

As mentioned in the previous section, following the [130] work, the next step is the improvement of the identified barriers by filtering and clustering of the identified barriers. In this case, a discussion with the moderators above-presented (Section 5.1.1.3) was conducted to carry out an inductive process to choose the psychological barriers related to BP. Based on the discussion, the barriers were clustered, filtered, added, or removed. Likewise, complex barriers were broken down into simpler ones.

The research team removed the variables *awareness* and *self-esteem related to PA* (which had both emerged from the literature review), as they concluded that these variables are very broad and complex, and involve emotional factors (e.g., anxiety, which is not necessarily related to BP), see TABLE 5.2. With regards to the variables from the external surveys [6], these were removed because they were indirectly addressed by the variables *confidence in one's body* and *perceived body appearance* (see TABLE 5.2, External survey: reported in BQPA*)*. It was considered that *confidence in one's body* addressed *Fear*.

For the IFiS survey (see TABLE 5.2, Survey: BQPA), it was considered that the *general physical fitness* factor can be reflected in one movement quality often mentioned in the literature, which is body *fluidity*. I was found out that the literature considers that a *fluid* movement is smooth and coordinated (e.g., a wave-like propagation through body joints) [132], [133]. It is worth mentioning that "smoothness" is defined as the continuity/fluency of movement through body joints accordingly with the speed of variation, but not abrupt changes in velocity or acceleration (standard deviations of velocity and acceleration) [134]. Following these movement qualities, such as fluency, control of movement, and velocity, it was necessary to break down the movement *fluidity* into more specific body capabilities. Then, the movement fluidity was worked together with the *general physical fitness* factor and its 4 factors (as defined in the IFiS questionnaire [45], [46]: *cardiorespiratory endurance*, *muscular strength*, *flexibility, and speed/agility*. It is worth

[3] This Ph.D. thesis was developed as part of the research project www.magicshoes.es. My contribution initiated in step 2, when developing a taxonomy, based on the work done by the team in the identification of barriers.

mentioning the variable *speed/agility* is related to the perceived power/energy/effort put into the movement.

For clustering, considering the information from the focus group, 4 barriers related to the capabilities or skills for performing PA emerged: Perceived *General physical condition*, Sense of *lack of balance*, the sense of *Feeling stuck*, and *Sense of absolute limits.* These are barriers that can be addressed individually but at the same time, these barriers are part of a bigger variable, called *Confidence in one's body* (or *Self-confidence* from the literature review). Moreover, the workshop grouped the *Lack of sense of progress/achievement* and *Lack of sense of absolute limits/measure against yourself* in a new cluster called *Movement progress,* which focused on proprioception and on providing perceptions of movement progress, see TABLE 5.2, focus group.

Lastly, *Emotional factors such as* anxiety or frustration can affect *Perceived body appearance* and *Confidence in one's* [25], [27], [38], [128]. However, it was decided to address these Emotional factors indirectly by working with the other body-related barriers. Given the intrinsic relation between BP and emotional factors it was expected that by addressing BP factors there would be a positive influence on the emotional factors, see TABLE 5.2.

TABLE 5.2: STEP 2 OF THE TAXONOMY, FILTERING AND GROUPING OF BARRIERS FOR PA THAT ARE RELATED TO BP.

Source	Original barriers/variable	Barriers after filtering and grouping
Literature Review [6]	Self-efficacy/Self-confidence	Part of **confidence in one's body**[a] (Self-confidence).
	Awareness	Removed due to its complexity and involving emotional factors.
	Fear	Confidence in one's body.
	Discipline, initiative, willpower and commitment Energy level (physical variable) Emotional/psychological state	Speed/agility Emotional state addressed indirectly through body-related barriers.
Survey: BQPA [6]	Self-confidence/self-esteem	Self-esteem removed.
	Knowledge	Confidence in one's body.
	Energy level (physical variable) Initiative, willpower, and commitment Emotional/psychological state Health/weight benefits	Addressed through speed/agility Emotional state addressed indirectly through body-related barriers.
	Awareness Self-efficacy Fitness status Pain or body sensations	Awareness and sense of being incapable to perform PA removed, they involve emotional factors.
	Challenge and difficulty	As the sense of frustration comes from the sense of challenging and difficulty this barrier involves emotional factors that are addressed indirectly through body-related barriers.
External survey: reported in BQPA [6]	Motivation (intrinsic to extrinsic): Autonomy, Competence, and relatedness	Confidence in one's body and **Perceived body appearance**.
	Self-esteem related to PA	Confidence in one's body and Perceived body appearance.
	Subjective importance of corporality; Physical attractiveness; and Care of physical appearance	Confidence in one's body and Perceived body appearance.
Survey: IFiS [45], [46]	Cardiorespiratory Endurance	**Cardiorespiratory Endurance.**
	Muscular Strength	**Muscular Strength.**
	Speed/Agility	**Speed/Agility.**
	Flexibility	**Flexibility.**

Source	Original barriers/variable	Barriers after filtering and grouping
	General physical fitness	**Perceived general physical condition**
Focus group	Movement progress	**Movement progress**: **Lack of sense of progress/achievement**.
	Solidity	Speed/Agility.
	Feeling Stuck	Sense of **feeling stuck** is part of Confidence in one's body.
	Sense of lack of balance	**Sense of lack of balance** is part of Confidence in one's body.
	Limits	Sense of absolute limits is part of Confidence in one's body and **movement progress**.
	Perceived power	Speed/agility.
	Anxiety and Vulnerability	They are addressed indirectly by working with other body-related barriers.
	Confidence in one's body	It is considered a bigger barrier that includes other body-related barriers.
	Perceived body fluidity	Clustered to Perceived general physical fitness which can be addressed individually as the perceptions of cardiorespiratory endurance, muscular strength, flexibility, and speed/agility.
	Self-esteem	Self-esteem removed.
a. Barriers that passed the filter or group other barriers were highlighted in bold		

5.1.3. Features or dimensions acted upon

Once the barriers were identified and grouped, the next step was to relate them to features or dimensions to act upon through technology, in order to address the barriers.

Firstly, the *Confidence in one's body* may be acted upon by **Enhancing proprioception** [25], [41]**.** Proprioception is defined as the sense of body parts position and the energy expended in the movement and the ability to separate joints from the whole [135]. Additionally, *Feeling stuck* may be addressed by acting on the perceived ability to **Initiate or continue the movement**. *Sense of lack of balance* may be acted upon by increasing the **Perceived balance**, **Proprioception**, and **Coordination**. Finally, *Perceived body appearance* may be addressed by acting upon the perception of **Weight**, **Size**, and **Shape** of the body.

Secondly, in relation to the Perceived physical condition, four factors were focused. *Cardiorespiratory Endurance* may be worked out by acting upon the **Perceived cardiorespiratory** condition and **Perceived resistance** and by means of **breathing control**. The *Muscular strength* may be worked out by acting upon the **Perceived muscle strength** and the **Perceived resistance**. The *Speed/Agility* and the perceived power may be worked out by acting on the **Perception of effort** employed in movement, and by alteration of Perceived **body weight** and Perceived **coordination,** leading to perceptions of moving faster or with more agility. The variable *Flexibility* may be worked out by acting upon the perceived **body flexibility** and **body elasticity**.

Thirdly, the *Movement progress* and limits are worked out by acting upon the **Perceived own limits** in terms of movement range/space or maximum amount of repetitions/time of exercise that one can possibly do, **and the perceived capability of overtaking those limits**.

5.1.4. Strategies and Movement-sound mappings

Once it was identified the features or dimensions that may be acted upon to support barriers, the Knowledge Base of interactive movement sonification was searched for mappings that have the potential to act upon the barriers to propose strategies. Following this, the next subsection summarizes and justifies the sonification choices made based on the Knowledge Base (see TABLE 5.3).

5.1.4.1. Strategies

TABLE 5.3: FEATURES OR DIMENSIONS ACTED UPON AND STRATEGIES TO ADDRESS BARRIERS RELATE TO BP IDENTIFIED IN THE LITERATURE REVIEW.

Num.	Features or dimensions acted upon	Strategies
1	Enhance proprioception	This may be achieved through movement sonification, such as sonification of limb angles during the movement and of impact events to provide position information [25], [27], [37], [119], [120]. For instance, [37] showed how movement perception and weight distribution in dancers, e.g., Sauté (a small jump) or plié (bends the knees), can be supported by using non-speech sounds for real-time movement sonification.
2	Enhance perceived body appearance	This may be achieved by employing sonification of impact events [17], [37], [119], [121]–[123]. For instance, altering footsteps sounds, by increasing the frequency components of the sound spectra, to make it appear to be produced by a lighter body [17], [119].
3	Increase perceived cardiorespiratory condition	This may be achieved by means of sonification that facilitates cardiorespiratory exercises [21], [125], sonification that facilitates breathing control [41], and by using sounds to shift the focus of attention so that the person does not focus on being out of breath or on their fast heartbeat [124], [136].
4	Increase perceived muscle strength and resistance	This may be achieved through sonification of impact events to alter perceived applied strength or resistance. For instance, real-time audio feedback (weak vs strong sounds) when tapping on a surface can change the perceived applied strength and the tapping behavior [17]. Another example is the use of sonification based on an action to make it sound as resulting in an "aluminum can crush" [117].
5	Enhance perceived speed/agility	This may be achieved through the sonification of coordinated movements imitating the slow or fast movement. For instance, in a study in [127], a teacher performed a particular movement and created a particular sound based on the movement characteristics (e.g., speed), which was recorded. A student tried to repeat the teacher movement; the more similar the student movement with respect to the teacher movement was, the more similar was the sound produced by the system to the one recorded by the teacher, allowing both student and teacher to know when and where they went off track. This could be complemented with changes in volume [17], as an increase in volume can increase speed (and direction of arm movement) [126]. For instance, a Wind sound, can also have an effect on

Num.	Features or dimensions acted upon	Strategies
		Perceived body weight, Perception of effort, and perceived coordination, see work on Section 4.4.3 [126].
6	Enhance perceived flexibility	This may be achieved through sonification of movement (angles) with continuous (windchimes, water sounds) vs discrete (short tones played at certain angles) sounds to alter perceived flexibility/fluidity [27], [41].
7	Provide perception of movement progress or achievement	It is possible to use movement sonification to reward small movements by adjusting the calibration of the movement range [27]; to employ sonification to mark the completion of movement [25], [38], [120]; and to sonify changes or make the sonification evolve with time to give impressions of body progression or goal achievement [25]. Through the use of this strategy body movement sensations may change from rigid/mechanical to fluid [41], [128], [129].
8	Encourage or invite movement ("body pulling")	This may be achieved through a discrete sonification, such as a musical scale (or the same tone) with the notes spaced equidistantly in a range of movement (giving feedback during the whole movement hence helping to keep moving) [27], [41], [128]; sonification of micro-movements, e.g., arm/hand motion accompanied by upward and downward scales. [129], [137], [138]; or through a sonification that "pulls your body" or changes your center of mass through sound changing in pitch to encourage continuation for instance, through sounds changing in pitch which may alter the perception of body position [16], [38].
9	Perceived balance	This may be indirectly addressed together with other strategies, such as sonification of coordinated movement, e.g., coordinate upper/lower limbs, by facilitating the perception of moving one's limbs separately; e.g. by sonifying the lower limbs with a sound with lower pitch than the sound used for sonifying the upper limbs; or assigning to the left and right lower limbs respectively left and right audio channels to get a natural spatial reference [129], [139]; sonification of movement angles [37], [120], [138]; or perhaps by means of sonification that "pulls your body" [37], [120], [138].
10	Emotional factors	It may be indirectly addressed by means of some of these strategies, such as by using sonification to encourage/invite movement to address fear and anxiety. [27], [38], [128]; or using sound to shift the focus of attention [23], [41], [125].

5.1.4.2. Movement-sound palette

Once the barriers and potential strategies to address them were identified, the mappings were designed considering different movements for the movement-sound palette. The included mappings are based on the strategies and the aim to stimulate different BP (e.g., feeling stronger or faster) through the sonification of movement. First of all, four exercises were chosen to work on them (see FIGURE 5.2), which corresponded to four different exercise programs, based on a handbook with recommendations for increasing PA: walking, warm-up (step-ups), stretching (thigh stretch), and strength (leg lift); the movements were specially selected to not involve vigorous activity but rather moderate activity given the low PA level of the target group [140]. These guidelines try to engage physically inactive people in exercise and give some instructions, such as warming up the muscles before engaging in the flexibility and strength program. For instance, the "step-ups" exercise was chosen because it allows the muscles to warm up, it covers building up cardiorespiratory condition, breathing control, coordination, and balance. "Leg lift" involves the challenge of building strength and toning. "Thigh stretch" allows building upon elasticity or flexibility, and it relates to a sense of movement control, and proprioception. Lastly, the "walking" program is the most recommended, complete, and natural exercise. The exercises were selected due to their characteristics as explained above, and these features allowed the design of the mapping sound.

Secondly, the sound mappings were designed through the application of a descriptor-based concatenative synthesis [116], which reproduces and edits samples of sounds using Max/MSP with a library called MuBu[4]. This method allows the analysis of data from sensors (more details in Section 5.2) and transforms a sound previously selected, analyzed, and edited, with the target of playing in real-time. It allows several interactions between the sensor's data to particular characteristics of the sound such as sound frequency.

[4] https://forum.ircam.fr/projects/detail/mubu/

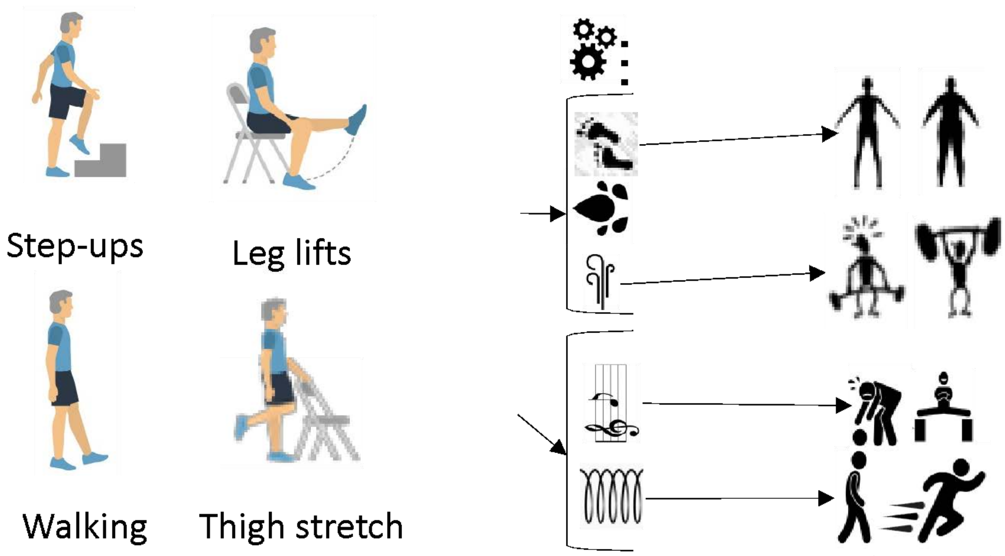


FIGURE 5.2: REPRESENTATION OF THE EXERCISE MOVEMENTS (“THIGH STRETCH”, “WALK”, “LEG LIFT”, AND “STEP-UPS”), MAPPED SOUNDS (“MECHANICAL/GEARS SOUND”, “NORMAL FOOTSTEPS”, “WATER”, “WIND”, ”SHORT A4 NOTE”, “ASCENDING”) AND POTENTIAL EFFECTS ON THE BP WHILE PEOPLE PERFORM THE EXERCISE (POTENTIAL EFFECTS: “PERCEIVED BODY WEIGHT”, “PERCEIVED MUSCULAR STRENGTH”, “PERCEIVED FLEXIBILITY”, “PERCEIVED SPEED/AGILITY”).

An iterative design cycle was followed, involving different pilot tests and studies. As a starting point, the first version of the prototype was used (explained in detail in Section 5.2.1) and studies were conducted to evaluate and refine the first version of the movement-sound palette that in each iteration incorporates additions, changes, or new versions of the different mappings and the device (see Section 5.2.2, and 5.2.3). The prototype is connected to a sensor of Force Sensitive Resistors (FSRs) placed under insoles in the front and back, and a band with a 9-axis IMU with an accelerometer, gyroscope, and magnetometers placed on the ankles.

A description of the mappings (first version) designed for each of the four exercises is listed below in TABLE 5.4:

TABLE 5.4: DESCRIPTION OF THE MOVEMENT-SOUND PALETTE PROPOSED TO SONIFY THE 4 MOVEMENTS: LATERAL ARM RAISE, WALKING, LEG LIFT, AND THIGH STRETCH.

Movements	Sound name	Description	Strategies to address psychological barriers to PA
Step-ups	Mapping 1: “ascending”	The sound is a “boing” effect acting as an initiation event when the foot releases the pressure on the front FSRs.	Strategy 8 and 9 - This sonification was aimed to encourage movement continuation (e.g., by activating a sound that “pulls the body”) [16], [25], [27], [41]
	Mapping 2: “Can-Crush”	The sound is a sample of an “aluminum can crush”, so as to give the sense of smashing a can of aluminum on the ground when the foot presses on the front FSRs. The values from the FSR allow to select samples of varying mean audio energy (the audio energy is accord to the FSR value)	Strategy 3 and 4 - This sonification intends to analyze the opportunity to stimulate body sensations, feeling a strong(er) or heavy(er) body, using this metaphor [117].
	Mappings 3: “Short A4 Note” Mappings 4: “Constant”	The sound is a flat/uniform sound based on a note sound (“Short A4 Note”) or a pure tone with a frequency of 400 Hz (constant) activated when the foot presses the front FSRs.	This sonification is not associated to any strategy but both sonifications are intended to be used as control stimuli for Mappings 1 and 2. Both have the same duration of the mappings and in both, there is no metaphor associated. Therefore, the sounds are used to control for the fact that just listening to a sound that accompanies the movement may have an effect.
Walking	Mapping 5: “Wind”	The sound is a continuous sound of “Wind”, which increases or decreases the volume during the movement of the foot (swing) of a step. When the foot releases the pressure on the front FSRs the sample sound is played; then, the movement intensity, measured by the accelerometers increases or decreases during the swing, then increases or decreases the volume of the sound. This sound is based on changes in frequency of pink noise.	Strategy 5 - This sonification intends to analyze the opportunity to change BP in terms of perceived velocity and movement "fluidity”, thus increasing perceived capabilities, for instance, feeling faster and feeling the movement more fluid (by the sense of being flying, going with the wind) [25], [41], [126].
	Mapping 6: “High Frequency Footsteps”	The sound is a pre-recorded sound of human footsteps but modified to augment the high frequency components (600 -1200 Hz).	Strategy 2, and 10 - This sonification intends to study the opportunity to alter the perceived body in relation to

Movements	Sound name	Description	Strategies to address psychological barriers to PA
		When the foot presses the back FSRs the "High frequency footsteps" sound is played.	size/weight, in the case of high frequencies that decrease the perceived body weight (e.g., by feeling a lighter body). Further, this sonification has potential to affect emotional state and speed (e.g., feeling more positive and faster) [17].
	Mapping 7: "Normal Footsteps"	A pre-recorded sound of human "normal" footsteps, i.e., which has not been modified in frequency, and that is activated when the foot presses the front FSRs.	Strategy 2, 3, and 10 - This sonification is used to compare the effects with the ones observed with Mapping 6. It is expected to result on a heavier perceived body than the perceived body when exposed to Mapping 6 [17].
	Mapping 8: "Long A4 Note":	The sound is a flat/uniform sound based on a note ("Long A 4 note") with frequency of 440 Hz which is activated when the foot presses on the front FSRs and the ankle moves the accelerometers. This sound has an average duration (0.8 segs.)	This sonification is not associated to any strategy but it is used as a control condition for Mappings 5, 6, and 7 to control for the fact that just listening to a sound that accompanies the movement may have an effect.
Leg lift	Mapping 9: "Wave":	The sound is a musical scale between two octaves (C2-B3), their notes are distributed in the movement based on a previous calibration with a minimum and maximum position. The sound uses the accelerometer and gyroscope data to map the angles of the movement and play the piano note.	Strategy 1 and 10 - The sonification changes/evolves with time to give impressions of body progression or achievement [25], [41].
	Mapping 10: "Underwater"	A continuous sound of water running (an underwater sound, i.e., low-pass filtered water sound) plays between the minimum and maximum position and a splash sound at movement start/end. The accelerometer and gyroscope data allow to map the sound to angle, e.g., identifying the maximum and minimum angle.	Strategy 2 and 10 - This mapping aims to use attention grabbing events/pleasant events to take attention away from one's body [25], [39].
	Mapping 11: "Note A" Mapping 12: "Flat"	The sounds are uniform sounds, the first one is based on a simple note (A4) and the second one is a pure tone with a frequency of 440 Hz. Both sounds are activated when the foot presses on the front	This sonification is not associated to any strategy but the sonifications "Note A" and "Flat" are used as control conditions for Mapping 9, 10 respectively. These sounds,

Movements	Sound name	Description	Strategies to address psychological barriers to PA
		FSRs and the ankle moves the accelerometers.	without associated metaphors, aim to control for the fact that just listening to a sound that accompanies the movement may have an effect.
Thigh stretch	Mapping 13: "Mechanical"	This sound of gears is mapped to movement angle changes. The angle value (of the gyroscope) allows choosing the varying average audio energy samples.	Strategy 1, 3, and 7 - This sonification intends to increase the feeling of movement control and proprioception through the addition of feedback about the body position, i.e., angle [41]
	Mapping 14: "Water drops"	The sound uses the accelerometer and angle data to map a continuous sound of water drops when raising/lowering the leg.	Strategy 1 - This sonification is used to evaluate if it is possible to increase proprioceptive awareness due to the sounds spaced during the movement trajectory [25], [41].
	Mapping 15: "Wind"	A continuous sound of "Wind" is played according to the angle changes of the gyroscope. This sound is based on changes in frequency of pink noise.	Strategy 1, 5, and 6 - As in the walking sound, this sonification proposes to study how to alter the speed and movement "fluidity", helping to feel faster and more fluid during the movement. In addition, this sound aims to study the effects in proprioceptive awareness considering the increase or decrease of volume when moving up/down the leg [25], [41], [126]
	Mapping 16: "Long A4 Note"	This sound plays a Long A4 Note as it does in the movement of walking; in this case, the sound is reproduced from the initial position to the end, ending the sound when it reaches the maximum position; it is based on the angle data, using the gyroscope.	This sonification is not associated to any strategy but it is used as control of Mappings 13, 14, and 15. The sonification "long note 4A" allows to control for the fact that just listening to a sound that accompanies the movement may have an effect.

Once the first version of the movement-sound palette was defined, the sonifications were added to a first version of the prototype (referred to as SoniShoes) that allows the interaction between the physically inactive adults and the sonification. In the following section, first a description of a previous prototype was introduced which informed the design of the SoniShoes prototype. Then, a second iteration of the prototype (SoniBand) was presented. Both SoniShoes and SoniBand are wearable prototypes that integrate sensors to obtain data of the people's bodily movements, and these data are used as information that allows the functioning of different movement-sound mappings.

5.2. Implementing SoniShoes & SoniBand

Here, the three prototypes are described: **MagicShoes**, **SoniShoes**, and **SoniBand**, and how they work. MagicShoes is a prototype that was already available at the beginning of this thesis work, and which informed the design of **SoniShoes** and **SoniBand**. The components of the hardware and software will be described, as well as the scheme of communication between the prototype and the general system.

5.2.1. MagicShoes

As introduced above, previous studies have shown that the altering of the footstep sounds produced while walking can have an effect on people's BP, emotions, and movement behavior [17], [33]. The MagicShoes prototype allows capturing and changing (in real-time) the frequency spectrum of the footstep sounds produced by a person walking. Previous results employing this prototype showed that the altered walking sounds made an effect on the participant's perceptions of their own body weight (i.e., leading them to feel thinner, changing their movement behavior, and enhancing their emotional state). The shoes (a pair of sandals) integrate an accelerometer and pressure sensors (2 per foot) that are connected to a microcontroller (Arduino) which sends the data captured (via Bluetooth) to a computer for analyzing the walking behavior later. Meanwhile, two microphones (positioned on the back of the shoe) connect to a Microphone Preamplifier (model SP-24B) that amplifies the acoustic signal of the footsteps sounds. Next, the sound signal passes through a Behringer MINIFBQ FBQ800 Ultra-Compact Graphic Equalizer with 9 frequency bands, to finally send the output back to the walker through a pair of Sennheiser RS220 headphones (see FIGURE 5.3).

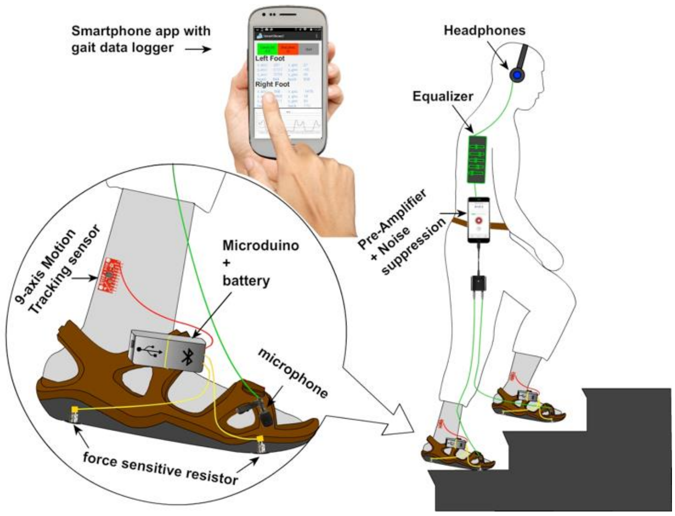


FIGURE 5.3: OVERVIEW OF THE COMPONENTS USED IN THE PREVIOUS PROTOTYPE [33].

In this prototype, there is no interactive sonification. It is limited to the use of sounds that one's body produces, and it can only be used in controlled contexts which must not be noisy. However, the work with this prototype emphasizes how the modification of sounds made through the body may change people's BP and potentially impact on PA.

In the next sections, the SoniShoes and SoniBand prototypes will be described. Both prototype systems allow the sonification of movements through the use of movement-sound mappings with the aim of changing the BP of the person as support during their PA. One of the changes in the most recent prototype (SoniBand) with respect to the first version of the prototype (SoniShoes) was to migrate the system from a computer to a portable device to permit a comfortable use in a realistic environment and update the sensor version of the hardware.

5.2.2. SoniShoes: desktop version

This prototype is based on the version by [141], with a new version emerging as the hardware and the movement-sound palette[5] were refined through the analysis of results of the pilot studies and the subsequent experimental studies with users (see Section 5.3). The SoniShoes is a portable prototype based on shoes with integrated movement sensors and a software tool applied in Max/MSP (Cycling'74, FIGURE 5.6), which "sonifies" the sensor inputs when the prototype is used. This software allowed the design and use of

[5] Once I joined the "MAGICSHOES" project the prototype was iterated and refined in terms of hardware and sonifications, following the methodology.

several gesture-sound mappings, meanwhile recording the information of the body movement to analyze the behavior.

FIGURE 5.4: SONISHOES, A DESKTOP VERSION FROM MAGICSHOES PROJECT [141].

The SoniShoes prototype (FIGURE 5.4) contains a wireless emitter (a BITalino R-IoT) with an Inertial Motion Unit (IMU) joined to two pressure sensors called Force-sensitive resistors (FSR). The BITalino R-IoT (v2 from Plux) embeds a 9-axis IMU sensor with 3 accelerometers, 3 gyroscopes, and 3 magnetometers, digitized at 16 bits. Only the accelerometers and gyroscopes axis data were relevant in our case and were captured. The FSRs which have 1.75×1.5″ of sensing area receive the force employed by feet on the ground and are located on the forefoot and high foot under insoles of a pair of strap sandals which protect the FSRs and improve comfort during the prototype use. The two pins extended from the bottom of the sensors were soldered with wires, and then covered by insulating tape. The prototype uses a Polymer Lithium Ion (Li-Po) Battery of 500mAh (10g, size 29 x 36 x 4.75 mm). The battery should be charged using the provided USB cable. The battery lifetime is ~10h with the standard battery. The battery typically takes 2,5h to charge. The prototype used the ergonomic and adjustable headphones Sennheiser HDR 220 (model RS 220), a circum-aural digital wireless with analog inputs. It is composed of a transmitter base to control which includes rechargeable integrated batteries for the wireless headphones. All above-mentioned electronic components are in FIGURE 5.5. The data obtained from the sensor are transmitted wirelessly (via Wi-Fi) to a computer with Max/MSP through the Open sound control (OSC) protocol.

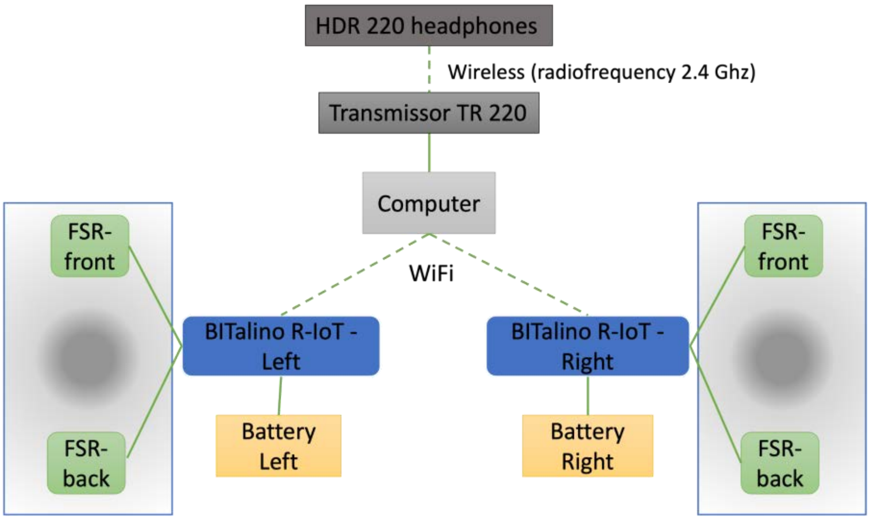


FIGURE 5.5: THE DIAGRAM SHOWS THE CONNECTION WITH THE COMPONENTS FOR EACH FOOT, FORCE-SENSITIVE RESISTORS (FSR) CONNECTED TO A R-IOT.

The Max/MSP was used, which is a visual programming language for the specialized needs of artists, educators, and researchers working with audio, visual media, and physical computing. Following this, Max patches were used, which are pieces of a program that allow for creating objects and connecting blocks of objects, with the objective of capturing, analyzing, and calibrating data received from the R-ioT board. For instance, the FIGURE 5.6 below illustrates the Max connection using OSC protocol with the R-ioT sensors, one for the right and one for the left foot with the port numbers 8888 and 9999 respectively. For example, one of the functions is to show the response of the accelerometer, position angles, and input from the FSRs connected to the R-ioT.

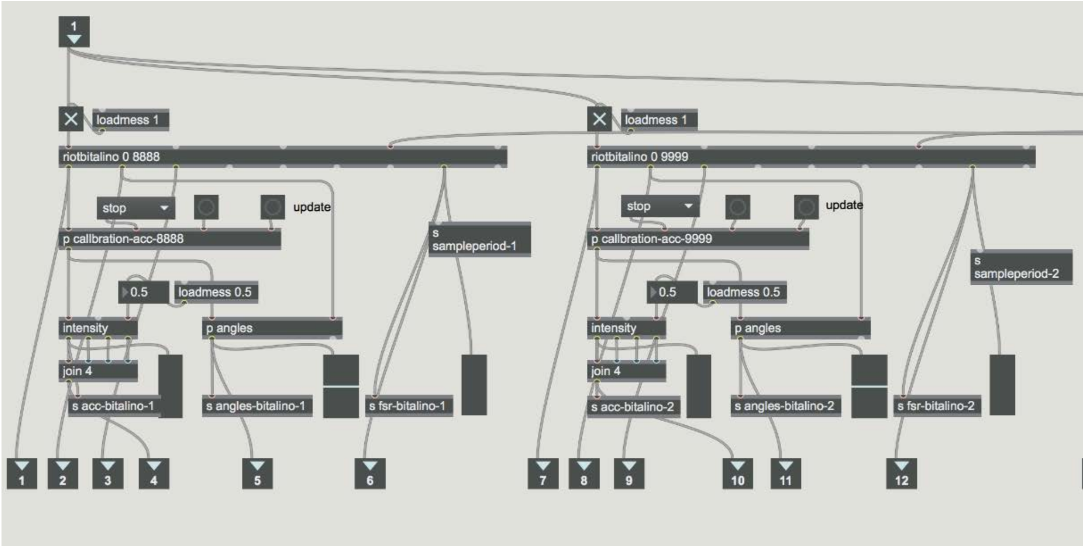


FIGURE 5.6: BITALINO PATCH WHICH CONTROLS BOTH R-IOT BOARDS AND ALLOWS VISUALIZING THEIR PERFORMANCE.

5.2.3. SoniBand: mobile version

In order to extend the research on the effects of sounds on BP to support PA to real-life contexts, we[6] designed SoniBand, a smaller and ubiquitous wearable device based on SoniShoes and [141]. The SoniBand contains a (wearable) band with sensors of movement and a smartphone. The wearable band (see FIGURE 5.7) is an auto adjustable band outfitted with a small hand-sewn fabric bag containing the BITalino R-IoT embedding a 9-axis IMU, the same model as in SoniShoes. Further, as in SoniShoes, the band and the smartphone send and receive wirelessly (using Wi-Fi) the data; however instead of a computer a small board computer is used, i.e., a Raspberry Pi Zero (with 1 GHz single Core CPU and 512MB of RAM), to receive the sensor value and play the movement sonification in real-time, as well as for storing the data. To make the communication between devices possible, a web application was developed (with Node.js and the Soundworks library) according to the needs of detecting angle changes of the arms and legs and sonify these limbs' movement.

[6] I and Joseph Larralde who is a software/hardware developer associated with the project contributed to implement this SoniBand prototype. The software uses the library Soundworks developed by Benjamin Matuszewski at Ircam [232].

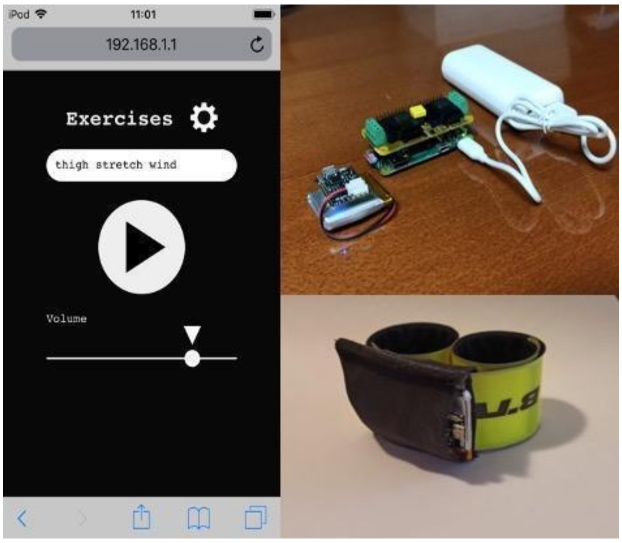


FIGURE 5.7: MOBILE VERSION WITH (LEFT) USER INTERFACE OF THE WEB APPLICATION; (RIGHT-UPPER) A R-IOT WITH BATTERY, AND RASPBERRY PI ZERO WITH COMPACT BATTERY; AND (RIGHT-LOWER) AN ADJUSTABLE BAND EQUIPPED WITH A HAND-SEWN CLOTH POCKET CONTAINING THE R-IOT.

The web application controls the Raspberry Pi Zero through the web navigator of the smartphone, FIGURE 5.7. This allows users to choose a specific sonification (from movement-sound palette) through a simple user interface, and to calibrate the device to the individual boundaries (angles) of the specific person's movements.

The calibration is a process that is needed in both prototypes. The calibration requires storing the information of the position of the body part, such as, start (minimum angle) and end (maximum angle) position to sonify in real-time these positions or the performed movement between them.

5.3. Evaluation studies

Following the Design Science Research Methodology for the design of solutions (mappings), in this case based on the barriers/factors that prevent PA, the second phase of the design cycle is the evaluation of the proposed solutions (FIGURE 1.3). The Evaluation phase aims to provide evidence for the specific objective (**SO3**: *"To evaluate the short-term and long-term effect of the movement-sound palette on BP, emotional state, and motor behavior in studies with physically inactive adults"*) and the research questions. The design iterations needed to answer the research questions which guided the implementation of the evaluations were carried out. To answer the second research question (**RQ2**: "*Which movement sonification strategies, through changes in body perception, have the potential to support PA to overcome their psychological barriers to PA?*"), one iteration was carried out in the initial stages that include an exploratory study that allowed to define the first steps of this thesis research. The evaluation phase considered the quantitative and qualitative approaches. Subsequently, three iterations were carried out based on a quantitative approach with the aim to analyze the effects of the sonifications on the movement behavior, emotional state, and body feelings (**RQ3**: "*How can we integrate movement sonification in wearable technology for PA and evaluate it in adults?*"). Finally, two iterations with a qualitative approach were carried out to analyze and understand the context of the participants through the interviews, body maps, and their diaries in a longer-term evaluation (**RQ4**: "*How can interactive sonification be used in the long-term and in everyday environments (i.e., in the wild) to overcome physical inactivity in physically inactive adults?*").

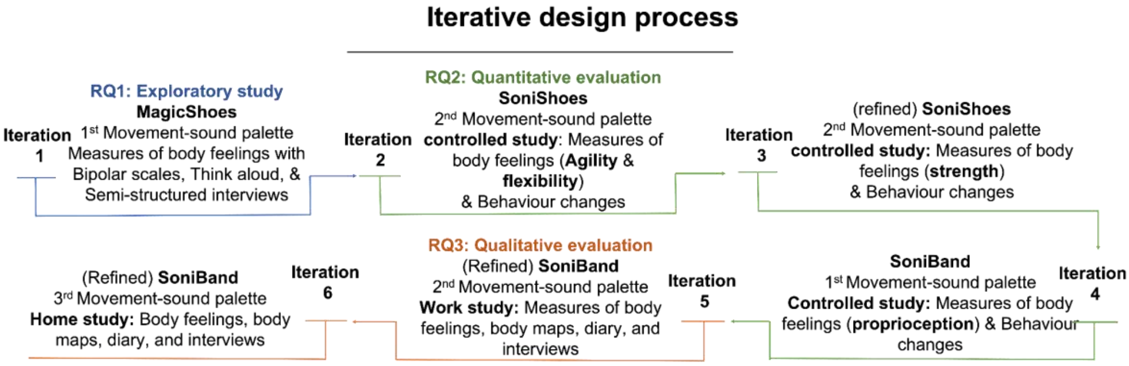


FIGURE 5.8: ITERATIVE PROCESS OF THEDESIGN CYCLE BASED ON THE RESEARCH METHODOLOGY (HEVNER, 2007).

5.3.1. Exploratory study

The **exploratory study** (FIGURE 5.8) proposes a proof-of-concept study to test the potential of the movement-sound mappings proposed to address the barriers to PA related to BP in adults when starting or while doing exercise. This study is a first step to answer the **RQ2** ("*Which movement sonification strategies, through changes in body perception, have the potential to support PA to overcome psychological barriers to PA?*")

Measures for the exploratory study were surveys about body and affective feelings (bipolar scales), (semi-structured) interviews, and a think-aloud technique. These will be further detailed in Chapter 6.

In brief, the **Bipolar scales** method was used to analyze the emotional state and body feelings of participants. While answering to the questionnaire using these scales, adult participants were invited to reflect and **comment aloud** about their body sensations, allowing us to get insight into how participants perceived the sound, their body, and their movements. The interaction was audio recorded with all the participants while they were filling in the questionnaire. This was followed by **semi-structured interviews** aimed to understand/clarify better the context of the answers to the bipolar scales.

5.3.2. Quantitative evaluation

In order to quantitatively evaluate the prototype with the sonifications, the design cycle of the design methodology was followed and the results of the exploratory study were considered, so that three controlled experiments were designed and implemented in a laboratory, FIGURE 5.8.

In these controlled studies, the deployment studies were divided into exercises and the investigated effects on one's own BP. Furthermore, these studies attempted to answer the third research question (**RQ3**) ("*How can we integrate movement sonification in wearable technology for PA and evaluate it in adults?*") They allowed us to know whether the sonification can be effective to facilitate PA by addressing barriers related to BP when performing specific exercises. These studies will be further detailed in Chapter 7.

In brief, the first study evaluated the sound effect in perceived coordination, agility, and flexibility for "walking" and "thigh stretch" exercises. The second study focused on "leg lift" exercises and muscular strength. The third study evaluated the influence of spatial metaphorical sounds in proprioception for a "lateral arm raise" exercise.

To measure whether there are bodily sensations and behavioral changes, a questionnaire and sensors were used respectively. A self-report of body changes (7-point Likert-scale response items) was employed for participants to report their body sensations, elicited by the sound when performing a specific exercise. The behavior changes were measured to study physical performance using data captured from the motion sensors attached to the ankle and shoe insoles during the "walk", "thigh stretch", "leg lift", and "side arm raise" exercises. For example: for "leg lift" and "lateral arm raise" exercises the maximum angle, acceleration, and velocity are measured; same for "walking", when the pressure applied on the ground is measured.

5.3.3. Qualitative evaluation

For qualitative evaluation, two qualitative studies centered on exploring the impact and effects of metaphorical sounds according to the results of the quantitative studies. Both studies aimed to answer the last research question (**RQ4**: "*How can interactive* *sonification be used in the long-term and in everyday environments (i.e., in the wild) to overcome physical inactivity in physically inactive adults?*") These studies will be further detailed in Chapter 8.

In brief, the first study comprised several sessions with physically active adults and aimed to understand the effects of the sonifications' characteristics on the perception of movement qualities, and their impact on PA. This study included specific exercises from the strength program (e.g., "squats"). For the second study, a home study with physically inactive adults was carried out with the aim to find which effects may help adherence to PA in this cohort of users. This second study covered exercises from the warm-up ("heel lift"), strength ("leg lift"), and flexibility ("thigh Stretch") programs.

5.4. Chapter Summary

This chapter presented the first step for the design phase. It presented the overview of the solutions in the design phase (strategies and mappings), it is based on the development of a taxonomy divided in 4 steps. Step 1 covers the identification of barriers related to body perception (literature review, interview, focus group). Step 2, filtering and grouping of the barriers. Step 3, features or dimensions on which action would be taken to direct the barriers of PA related to BP. Step 4, a series of strategies and movement-sound palettes (for the "walk", "step-ups", "thigh stretch", and "leg lift" movements) were proposed for the barriers identified. Following with the design phase, three prototypes were designed to implement the strategies and mappings in them, the MagicShoes prototype [17], [141], two more prototypes were created SoniShoes (desktop version) and SoniBand (portable version). Finally, this chapter introduced the studies for the quantitative (Chapter 7)) and qualitative (Chapter 8) evaluation of the prototypes and their palettes, beginning with an exploratory study (Chapter 6). These prototypes throughout the design phase, allow answering the objectives and research questions proposed in the chapter 1 following the iterative process of the design cycle based on the research methodology [43].

In the next chapter, this thesis presents the exploratory study with the MagicShoes prototype to assess in each mapping (with their mappings) and to answer the **RQ2**.

6. EXPLORATORY STUDY

In the previous chapters, the problem identification and iterative methodology (see Chapter 3) for all the studies conducted in this research were presented; and it was introduced the proposed solutions (see Chapter 5) to address the barriers to PA in physically inactive adults. This chapter presents the evaluation phase to assess the proposed solutions and address the (**SO2**) and the second research question (**RQ2**): "*Which movement sonification strategies, through changes in body perception, have the potential to support PA to overcome psychological barriers to PA?*

6.1. Exploratory study: Understanding the use of movement sonification in adults

Conducting exploratory studies is important, as they allow to generate the evidence needed to make decisions on how to proceed with the following studies and the research [142], [143]. As in previous chapters were mentioned (Chapters 1 to Chapter 4), there is a gap in the design of technology to address psychological barriers to PA. Therefore, an exploratory study was carried out with two aims. The primary aim of the study was to explore the possible effects on bodily movement, proprioceptive awareness, or bodily feelings of various movement-sound mappings designed to address a set of psychological barriers related to PA (e.g., Feeling Stuck, Lack of sense of progress [27], [41]) or related to BP (e.g., feelings of poor flexibility, movement control, or fluidity [40], [126]) in adults to facilitate engagement in PA, see also Section 5.1.4.1 of strategies. The secondary aim of this exploratory study was to re-design (whether is needed) the movement-sound mappings and the wearable device, based on the study findings, to ensure tackling the barriers that prevent PA.

6.1.1. Author contributions and related publication

In this study, I was responsible for the recruitment, acquisition, and analysis of the data. This thesis contributed to the conception and design of the work; the development of the sonification mappings and the software and hardware for such movement sonification and data acquisition; as well as the interpretation and writing of the study with supervision from other senior researchers from the research team.

6.1.2. Methods

6.1.2.1. Participants and setting

A study with 9 participants (M_{age}= 26.44, SD_{age}= 5.24, Range= 19 – 37 years; n= 3 females, 6 male) was conducted. The study was approved by the Ethics Committee of Universidad Carlos III de Madrid and conducted following the ethical principles of the Declaration of Helsinki for human testing. All the participants were volunteers in the study and they didn't receive monetary compensation (Appendix C). The study took place in a classroom with several tables put together for their use during the study.

Prior to the study, participants were informed about the study aims and procedure through an information sheet and were provided with an informed consent form. Participants were also required to complete two surveys: the International Fitness Scale (IFiS) ([45]; Spanish version validated in [44]) and the International Physical Activity Questionnaire (IPAQ) [67], [144]. Both surveys were used to collect data on the participants' perceptions of their physical fitness and their current level of PA, not to filter the participants, which allowed to characterize the participants' sample in the study. Note that these surveys were used as filters in the subsequent studies (Chapters 7 and 8), in which separate studies focused on a specific barrier and the effects of auditory feedback on this barrier were conducted.

Of 9 adults, three reported to have moderate PA levels (< 2319.5 MET/week), and six had a high PA level (> 3546 METS/week). Participants' perceptions of the level of physical fitness using the median and range IFIS scores, indicated that participants considered their general physical fitness level to be "average" that is a median = 3 (with a range of 2 – 4). Participants also reported an "average" 3 (2 – 5) cardiorespiratory condition, e "average" 3 (2 – 4) muscular strength, and "average" 3 (1 – 4) speed/agility. Lastly, for flexibility, it was observed that ratings were close to the "Poor" median score of 2 (1 – 3).

6.1.2.2. Apparatus and stimuli

a) MagicShoes prototype

The MagicShoes prototype, already introduced in Chapter 5 (see Section 5.2.1), was employed. As previously explained, this prototype includes two force-sensitive resistors (FSRs) in the shoe insoles and a 9-axis movement sensor (IMU) worn on the lower leg.

It is connected via Wi-Fi to the software Max/MSP which allows movement sonification, see FIGURE 6.1.

FIGURE 6.1: OVERVIEW OF THE WEARABLE PROTOTYPE, MAGICSHOES [141].

b) Exercises and sound stimuli

The exercises participants were asked to perform were “step-ups”, “walk”, “leg lift”, and “thigh stretch”. The sonification conditions for each of these exercises were described in Section 5.1.4.2. An overview of these conditions is presented in TABLE 6.1. Variations of note A in each movement were included as a control condition. For instance, “Long 4A Note” is a neutral sound played in order to control for the fact that just listening to a sound that accompanies the movement may have an effect.

TABLE 6.1: EXPERIMENTAL MOVEMENTS, CONDITIONS, TIME, OR NUMBER OF REPETITIONS.

Movements	Sonification	Time/repetitions
Step-ups	No Sonification	4 repetitions per leg (8 steps)
	Ascending	
	Constant	
	Can-crush	
	Short A4 Note (control)	
Walk	No Sonification	40 secs.
	Wind	
	Long A4 Note (control)	
	High-Frequency Footsteps	
	Normal Footsteps	
Leg lift	No Sonification	4 repetitions per leg (8 steps)
	Wave	
	Flat	
	Underwater	
	Note A (control)	
Thigh stretch	No Sonification	4 repetitions Hold 5 seconds and relax
	Mechanical	
	Water drops	
	Wind	
	Long A4 Note (control)	

6.1.2.3. Measures

a) Questionnaire data:

For data collection, a set of **bipolar scales** (with 16, 7-point Likert-type response items) were used to invite people to reflect and comment aloud about their body sensations, which allowed to get insight into how participants perceived the sound, their body, and their movements [145], see FIGURE 6.2.

- The first eight bipolar pairs were preceded by the sentence "As I was doing the exercise, I felt…" and ranged between the following terms:
  - calm (1) – excited (7), **Arousal**
  - uncontrol (1) – control (7), **Movement control**
  - light (1) – heavy (7), **Weight**
  - unpleased (1) – pleased (7) with the appearance of my body, **Body appearance**
  - my breath or heartbeat were/weren't accelerated during the exercise, **Cardiorespiratory condition**
  - weak (1) – strong (7), **Strength**
  - slow (1) – quick (7), **Speed**
  - agile (1) - not agile (7), **Agility**
  - not flexible (1) – flexible (7), **Flexibility**
  - not tired (1) – tired (7), **Tiredness**
- Three more items initiated with "I felt my movements were" and ranged between the following terms:
  - easy (1) – difficult (7), **Difficulty**
  - uncoordinated (1) – coordinated (7), **Coordination**
  - not fluid (1) – fluid (7), **Fluidity**
- The last items were the following:
  - "I felt" capable (1) - incapable "of completing the exercise" (7), **Capability**
  - "I felt" I could not tell (1) - could tell exactly "where my foot was" (7), **Proprioception**
  - "The sound I heard was" from Not produced (1) - produced by me (7), **Agency**

b) **Semi-structured interview:**

A short interview with three different open questions related to the ratings on the bipolar scales provided by participants was conducted:

1. "How did you feel with your body while you were listening to the different sounds?"
2. "Compare the sounds in each bipolar scale"
3. "Which of the sounds do you think matches the specific movement better?"

FIGURE 6.2: (LEFT) THE LAYOUT OF ROOM FOR THE EXPLORATORY STUDY TO ACCOMMODATE THE SURVEYS AND (RIGHT) BIPOLAR SCALES THAT ALLOWED QUANTIFYING PARTICIPANTS' BODY FEELINGS (SHEET, 89.1 X 42 CM). DIFFERENT COLOR LABELS WERE USED TO IDENTIFY EACH SONIFICATION CONDITION [145].

6.1.2.4. Experimental procedure

A within-subject design approach was used where all participants performed all exercises under all the different sonification conditions. A summary of the experimental procedure is presented in FIGURE 6.3. Participants were fitted with the SoniShoes and introduced to all the tasks and to the bipolar scale tool employed for data collection. There were four experimental blocks, one for each exercise, which participants completed in a randomized order. In each experimental block, first, participants were asked to choose a color label that would identify the sonification in that condition. Second, the participants performed the exercise in turn ("step-ups", "walk", "leg lift", or "thigh stretch") without sound. Third, they were asked to think-aloud about their body sensations and to fill in the predetermined bipolar scales laid on the table [145] (see FIGURE 6.2), while they were audio recorded. Additional questions followed to understand/clarify better the context of the answers. Fourth, the participants repeated the previous process with each sonification and the same exercise (see FIGURE 6.3).

After completing the four exercise experimental blocks, participants were asked to reflect on their answers. A short interview was conducted with three open questions related to the ratings on the bipolar scales provided by participants (see Measures). The interviews with participants were audio-recorded.

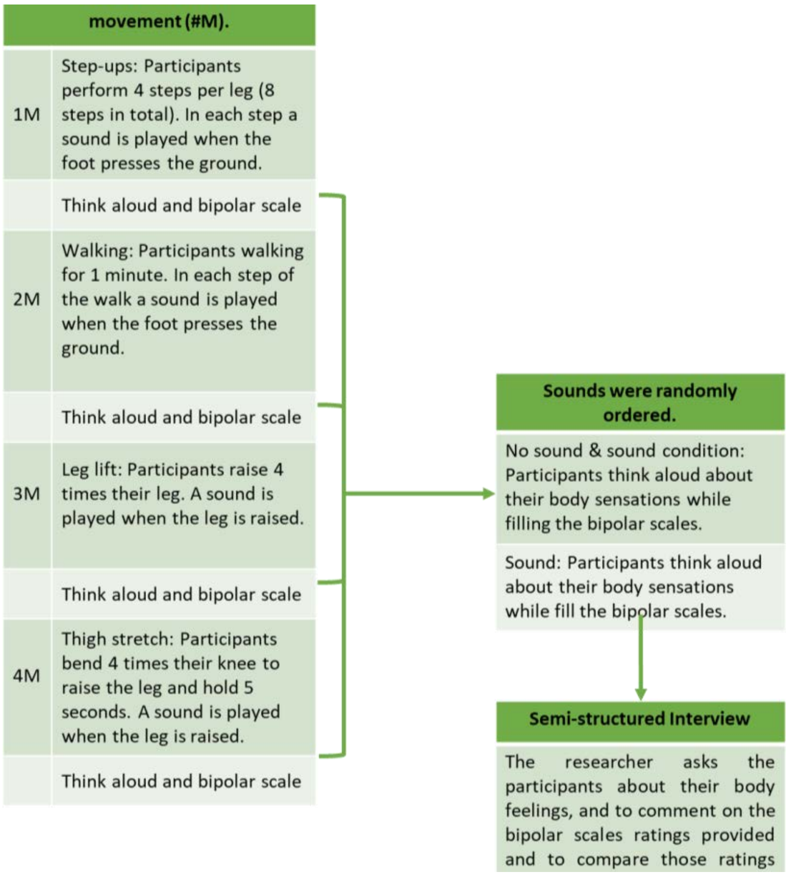


FIGURE 6.3: GRAPHICAL REPRESENTATION OF EXPERIMENTAL PROCEDURE (SONIFICATIONS ORDERED RANDOMLY, HTTPS://WWW.RANDOM.ORG/LISTS/).

6.1.2.5. Data analysis

First, a quantitative approach was followed to analyze the body feelings (survey) of the participants after each sound condition, and second, a qualitative approach to analyze their thoughts out loud. The think-aloud sessions with participants were recorded, transcribed, and analyzed. This study focused on identifying potential quotes where participants describe their feelings in relation to the sound during the exercise.

Despite this exploratory study contains a small sample size (which normally imply that the quantitative results should be interpreted with caution), statistical analyses performed offer guidance on large effects sizes.

Therefore, the study follows a deductive analysis, based on quantitative data that is the bipolar scales in combination with the think-aloud technique. Hence, the idea is to explore the viability and potential usefulness of an alternative approach through the questionnaires with bipolar scales that allow to guide and support the qualitative data [145], for future research involving controlled studies.

For questionnaire data, to analyze the effect of each sound condition, it was conducted a non-parametric Friedman test and Wilcoxon test to compare "No Sonification", "Ascending", "Constant", "Can-crush", and "Short A4 note". It is appropriate to employ non-parametric tests for surveys with Likert-type response items [146]. The significance level for all statistical tests was fixed as $p < .05$, and complemented with the corresponding effect size statistic: calculated using the formula: $r = Z/\sqrt{N}$ (large effect is .5, a medium effect is .3, and a small effect is .1), r is computed dividing the Z value by square root of N, where N is the number of participants [147]. Statistical analysis was performed by using Statistical Package for the Social Sciences (SPSS) Statistics 26 Data Analysis.

6.2. Results

This section presents for each movement the categories from the bipolar scale (e.g., arousal, control of movement). Overall, results showed that participants enjoyed using the SoniShoes and were aware that their movements produced sounds.

6.2.1. Effects of sound condition on body feelings for the four exercises

6.2.1.1. Effects of sound condition for the "step-ups" exercise

The Friedman test showed a significant effect of sonification in cardiorespiratory condition ($X^2(4) = 9.885, p = .042$); as shown in TABLE 6.2 participants report that the "Constant" ($z = -2.000, p = .046, r = .666$) and "Can-crush" ($z = -2.050, p = .040, r = .483$) sonifications gave them the feeling of their breath or heartbeat being accelerated more than with "No Sonification"; moreover, participants felt their heartbeat and breath was more accelerated with "Short A4 Note" than with "Can-crush"($z = -2.041, p = .041, r = .481$). In addition, there was a significant effect of sonification in agency ($X^2(4) = 15.378, p = .004$), that is, the feeling participants had that the sound was produced by themselves. The participants felt more agency when performing the "step-ups" with their natural footsteps, i.e., in the "No Sonification" condition than with “Can-crush” ($z = -2.257, p = .024, r = .532$); and “Short A4 Note” ($z = -2.108, p = .035, r = .497$); the “Constant” sound gave a higher sense of agency than the “Ascending” ($z = -2.041, p = .041, r = .680$) and “Can-crush” ($z = -2.060, p = .039, r = .485$) sounds.

TABLE 6.2: MEDIAN (RANGE) QUESTIONNAIRE SCORES (7-LEVEL LIKERT-TYPE RESPONSE ITEMS) FOR THE “STEP-UPS” EXERCISE. * AND ^ RESPECTIVELY MARK SIGNIFICANT AND A TENDENCY TOWARDS SIGNIFICANT MEDIAN DIFFERENCES.

Scales	**Step-ups exercise**				
	No Sonification	**Ascending**	**Constant**	**Can-crush**	**Short A4 note**
Arousal/Excitation^	4 (1 – 4)	5 (2 – 5)	4 (2 – 6)	4 (1 – 6)	4 (1 – 7)
Movement control^	6 (3 – 7)	4 (3 – 6)	5 (2 – 7)	5 (3 – 6)	5 (3 – 7)
Weight	4 (3 – 7)	5 (3 – 6)	5 (3 – 7)	5 (4 – 7)	4 (4 – 6)
Body Appearance	4 (3 – 7)	4 (2 – 6)	5 (2 – 7)	4.5 (2 – 6)	4 (1 – 7)
Cardiorespiratory condition*	4 (1 – 5)	4 (2 – 5)	4 (1 – 5)	4 (2 – 7)	4 (1 – 5)
Strength	4 (3 – 7)	4 (1 – 5)	4 (2 – 5)	4 (2 – 6)	4 (3 – 6)
Speed	4 (4 – 7)	5 (3 – 7)	4 (3 – 5)	4 (3 – 7)	5 (3 – 7)
Agility	4 (2 – 7)	4 (4 – 6)	4 (2 – 6)	5 (3 – 7)	4 (3 – 6)
Flexibility	4 (2 – 7)	5 (3 – 6)	4 (3 – 6)	5 (2 – 7)	4 (3 – 6)
Tiredness	4 (1 – 5)	4 (2 – 6)	3 (2 – 5)	4 (1 – 5)	4 (1 – 5)
Difficulty	2 (1 – 6)	3 (1 – 6)	3 (1 – 6)	2 (1 – 6)	2 (1 – 6)
Coordination	7 (3 – 7)	5 (3 – 7)	6 (3 – 7)	5 (5 – 7)	6 (2 – 7)
Fluidity	6 (3 – 7)	5 (2 – 7)	6 (3 – 7)	6 (4 – 7)	6 (2 – 7)
Capability	7 (2 – 7)	6 (3 – 7)	6 (4 – 7)	7 (4 – 7)	6 (3 – 7)
Proprioception	7 (1 – 7)	6 (1 – 7)	6 (1 – 7)	6 (1 – 7)	6 (1 – 7)
Agency*	7 (1 – 7)	1 (1 – 7)	3 (1 – 7)	2 (1 – 6)	3 (1 – 7)

Unless there was non-significant difference between conditions in arousal ($X^2(4) = 9.315, p = .054$). The results, as can be seen in The Friedman test showed a significant effect of sonification in cardiorespiratory condition ($X^2(4) = 9.885, p = .042$); as shown in TABLE 6.2 participants report that the “Constant” ($z = -2.000, p = .046, r = .666$) and “Can-crush” ($z = -2.050, p = .040, r = .483$) sonifications gave them the feeling of their breath or heartbeat being accelerated more than with “No

Sonification"; moreover, participants felt their heartbeat and breath was more accelerated with "Short A4 Note" than with "Can-crush"$(z = -2.041, p = .041, r = .481)$. In addition, there was a significant effect of sonification in agency $(X^2(4) = 15.378, p = .004)$, that is, the feeling participants had that the sound was produced by themselves. The participants felt more agency when performing the "step-ups" with their natural footsteps, i.e., in the "No Sonification" condition than with "Can-crush" $(z = -2.257, p = .024, r = .532)$; and "Short A4 Note" $(z = -2.108, p = .035, r = .497)$; the "Constant" sound gave a higher sense of agency than the "Ascending" $(z = -2.041, p = .041, r = .680)$ and "Can-crush" $(z = -2.060, p = .039, r = .485)$ sounds.

TABLE 6.2, showed that the "Ascending" sound $(z = -2.456, p = .014)$ gave the feeling of being more excited than the "No Sonification" condition. Moreover, regarding the feeling of being in control of the movements, the results showed a difference between conditions (*) in movement control, it was non-significant $(X^2(4) = 8.424, p = .077)$, due to the participants feeling more in control with "No Sonification" than with the "Ascending" condition $(z = -1.983, p = .047, r = .047)$.

The results for other questionnaire items indicated no significant differences between the sound conditions in the "step-ups" exercise. Results related to the sense of weight, body appearance, strength, speed, agility, flexibility, and tiredness, indicated the participants had a neutral feeling on these bipolar scales. For the items of movement difficulty, coordination, fluidity, capability, and proprioception, results showed that participants felt they were capable of performing the movement, which they could perform with ease, that their movements were coordinated and fluid, and that they kept a high sense of proprioception for all the sonification conditions. However, the sense of agency was kept only with the natural sounds produced during the movement (see below point d. No Sonification: Higher sense of agency). Therefore, even when there were no significant differences between the sonifications in the aforementioned bipolar scales, the sonifications do not prevent the proper performance of the movement.

In Measures is mentioned (Section 6.1.2.3), the results of the survey are complemented with bipolar scales with the thinking of the participants.

a) Effects on emotional state

As it can be seen in The Friedman test showed a significant effect of sonification in cardiorespiratory condition ($X^2(4) = 9.885, p = .042$); as shown in TABLE 6.2 participants report that the "Constant" ($z = -2.000, p = .046, r = .666$) and "Can-crush" ($z = -2.050, p = .040, r = .483$) sonifications gave them the feeling of their breath or heartbeat being accelerated more than with "No Sonification"; moreover, participants felt their heartbeat and breath was more accelerated with "Short A4 Note" than with "Can-crush"($z = -2.041, p = .041, r = .481$). In addition, there was a significant effect of sonification in agency ($X^2(4) = 15.378, p = .004$), that is, the feeling participants had that the sound was produced by themselves. The participants felt more agency when performing the "step-ups" with their natural footsteps, i.e., in the "No Sonification" condition than with "Can-crush" ($z = -2.257, p = .024, r = .532$); and "Short A4 Note" ($z = -2.108, p = .035, r = .497$); the "Constant" sound gave a higher sense of agency than the "Ascending" ($z = -2.041, p = .041, r = .680$) and "Can-crush" ($z = -2.060, p = .039, r = .485$) sounds.

TABLE 6.2, the results show that participants felt more excited with the "Ascending" sound than with the "No Sonification". One of the participants commented that with this sound he did not feel calm:

"— *Well, it could be that I am more flexible, but I don't feel calm*." [P2]

Moreover, other participants commented that the "Constant" sound made them feel calm and did not alter their emotional feelings.

"— *The last one (Constant sound) It was calmer*." [P3]

"— *The third (Constant sound) like a bell, nothing out of the ordinary.*" [P7]

b) "Ascending" sound: effects on movement control, speed, and agility

The survey results suggested that the "Ascending" sound gave the sense of being with less control of the movement than the "No Sonification". This was confirmed by one participant:

"— *The (Ascending) sound feels rare, like with less control.*" [P1]

Participants commented that they did not identify when the sound of each step finished, which could be related to the sense of losing control of their movement:

"— *The (Ascending) sound (from one foot) continues until the other (foot) starts, keep sounding, then I don't know where the movement of one foot is, in relation to the other foot, but it is more comfortable*." [P3]

However, during the interview, participants showed a positive attitude towards the "Ascending" sound and explained that this sound prompted them to step up with care:

"— *You feel like you are in a video game, jumping, so it's like you step carefully*." [P4]

Even with this sense of less movement control participants imagined themselves playing and jumping inside of a video game, feeling like a videogame character where the movement and body qualities (e.g., agile/speed or flexible) of the character increase:

"— *In first place… it feels like a springboard, it (Ascending) gives me the sense of it being elastic… like in the videogames when you jump over some object.*" [P6]

"— *This (Ascending) is a little more similar to a jump, but a little funny, it looks like the movement you do to climb stairs*." [P5]

c) "Can-crush" sound: effects on weight, cardiorespiratory condition, speed, capability, and proprioception

According to the survey, with the "Can-crush" sound, participants felt their breath or heartbeat was more accelerated than with the "Constant" and "No Sonification" conditions. Participants explained that even when the "Can-crush" sound didn't like them at all, it helped them to know where their feet were. One participant said:

"—*Very interesting, I didn't like this sound, it was not pleasant; but the difference is that this (Can-crush) sound gave me a more real awareness of my steps.*" [P4]

Moreover, the characteristics of this sonification (e.g., discrete trajectory and start/end position) were associated to discrete "cracks", which gave participants a sense of lightness and change of speed during the exercise:

"— … *the sounds that were like 'cracks' (Can-crush sound), when I moved my leg, they gave me an understanding of the trajectory of my leg*." [P2]

"— *The sound which is like a 'crack' feels like crashing an empty aluminum bag, you know, the more you press, the more it sounds. It gave me that same feeling that my step is slower or faster, because of the type of sound*." [P4].

d) No Sonification: Higher sense of agency

The survey results showed that the “No Sonification” condition gave a higher sense of agency compared with the “Can-crush” and “Short A4 Note” sonification conditions. This suggests that both sonifications need to be improved to give the participants the perception of generating the sound through their body compared with the “No Sonification” condition. On the other hand, comparing the “Constant” and the “Ascending” sound, participants felt more sense of agency with “Constant” than with the “Ascending” sound, which seemed more a “bell” sound acting like a guide but not as part of the body:

“— *I felt that I was with a bell that accompanied me while I was walking, like if I had something tied to me and while I walk it sounds, but that isn’t my own body*.” [P2]

6.2.1.2. Effects of sound conditions for the "walk" exercise

TABLE 6.3: MEDIAN (RANGE) QUESTIONNAIRE SCORES (7-LEVEL LIKERT) FOR THE "WALK" EXERCISE. * AND ^ RESPECTIVELY MARK SIGNIFICANT AND A TENDENCY TOWARDS SIGNIFICANT MEDIAN DIFFERENCES.

Scales	**Walk exercise**				
	No Sonification	**Wind**	**Long A4 Note**	**High-Frequency Footsteps**	**Normal Footsteps**
Arousal/Excitation*	4 (1 – 4)	5 (2 – 7)	5 (4 – 6)	4 (2 – 6)	4 (3 – 5)
Movement control	5 (4 – 7)	4 (1 – 7)	4 (2 – 7)	4 (1 – 6)	4 (3 – 7)
Weight	5 (3 – 7)	6 (3 – 7)	6 (4 – 7)	5 (4 – 6)	4 (1 – 6)
Body appearance	4(1 – 7)	4 (3 – 7)	5 (2 – 7)	4 (1 – 7)	4 (2 – 6)
Cardiorespiratory	4 (1 – 4)	5 (1 – 6)	4 (1 – 5)	4 (1 – 6)	2 (2 – 6)
Strength	4 (4 – 7)	4 (3 – 6)	5 (3 – 7)	4 (3 – 6)	4 (3 – 6)
Speed*	4 (3 – 7)	4 (3 – 6)	5 (4 – 7)	4 (2 – 6)	4 (2 – 6)
Agility	4 (2 – 7)	5 (3 – 6)	4 (3 – 7)	4 (2 – 6)	3 (1 – 6)
Flexibility^	4 (4 – 7)	5 (3 – 7)	5 (3 – 7)	4 (2 – 6)	3 (2 – 6)
Tiredness	4 (1 – 7)	4 (1 – 5)	3 (1 – 4)	3 (2 – 7)	3 (2 – 7)
Difficulty	1 (1 – 4)	2 (1 – 5)	3 (1 – 4)	2 (1 – 7)	2 (1 – 6)
Coordination^	7 (4 – 7)	6 (2 – 7)	6 (2 – 7)	4 (1 – 7)	6 (3 – 7)
Fluidity^	7 (4 – 7)	6 (4 – 7)	6 (2 – 7)	5 (1 – 7)	6 (2 – 7)
Capability	7 (4 – 7)	6 (4 – 7)	6 (4 – 7)	6 (1 – 7)	6 (2 – 7)
Proprioception*	7 (1 – 7)	5 (2 – 7)	4 (1 – 7)	5 (1 – 7)	7 (3 – 7)
Agency*	7 (1– 7)	2 (1 – 5)	1 (1 – 7)	2 (1 – 6)	3 (1 – 7)

The Friedman test showed significant effects of sound condition in arousal($X^2(4) = 12.15, p = .016$): with the "Long A4 Note" sound participants felt more excited than with "No Sonification" ($z = -2.555, p = .011, r = .602$), "Normal Footsteps" ($z = -2.070, p = .038, r = .487$), and "High-Frequency Footsteps" ($z = -1.897, p =$

$.058, r = .447)$. There were also significant effects of sound condition in speed ($X^2(4) = 9.78, p = .044$), as participants perceived themselves faster with "Long A4 Note" than with "Normal Footsteps" ($z = -2.363, p = .008, r = .621$). Proprioception was also significantly affected by the sound condition ($X^2(4) = 9.76, p = .045$): results showed that the sense of knowing where one's feet were during the movement is higher with the "Normal Footsteps" as compared with the "Wind" ($z = -2.060, p = .03, r = .485$), also it is higher with "Normal Footsteps" as compared with "Long Note A4"($z = -1.997, p = .046, r = .470$). Lastly, agency was significantly affected by sound ($X^2(4) = 15.83, p = .003$): participants had a higher sense with "No Sonification" than the sounds their heard were produced by themselves with "Long A4 Note"($z = -2.229, p = .026, r = .525$), "Wind" ($z = -2.536, p = .011, r = .597$), and "High-Frequency Footsteps" ($z = -2.041, p = .041, r = .481$). This may be because they understood that in that condition there is no sound and therefore the feeling of not producing any sound is created. Moreover, the sense of agency was higher with "Normal Footsteps" than with "High-Frequency Footsteps" ($z = -2.636, p = .008, r = .621$).

Apart from those significant effects, there were other non-significant, there was a difference between conditions (*), worth mentioning. With regards to flexibility ($X^2(4) = 8.92, p = .063$), participants felt more flexible with "No Sonification" than with "Normal Footsteps" ($z = -2.456, p = .014, r = .578$), and with "Wind" than with "Normal Footsteps" ($z = -2.041, p = .041, r = .481$). In relation to coordination ($X^2(4) = 9.10, p = .059$), results showed that with "No Sonification" the movement felt more coordinated than with the "Long A4 Note" ($z = -2.041, p = .041, r = .481$) and "High-Frequency Footsteps" ($z = -2.232, p = .026, r = .526$). Finally, with regards to fluidity ($X^2(4) = 8.59, p = .072$), participants perceived their movements were more fluid with "No Sonification" than with "High-Frequency Footsteps" ($z = -2.203, p = .028, r = .519$).

There were no significant differences between conditions for the items of movement control, weight, body appearance, cardiorespiratory condition, strength, agility, and tiredness, which were all close to the neutral score (4) of the scale (which ranged from 1 – 7). In the case of the sense of difficulty, the participants found it easier to perform the movement with the sounds than without the sound.

The results of the survey (Section 6.1.2.3) were complemented with the thinking of the participants while they were responding to the items and comparing the sonifications.

a) Effects on emotional state

The survey results showed significant differences in arousal, as participants felt more excited with the "Long A4 Note" than with "No Sonification", "Normal Footsteps", and "High-Frequency Footsteps". With regards to the emotional state elicited by the "Long A4 Note", some participants found it neutral:

"*— This (Long A4 Note) sound is nice. It is pleasant to the ear… this sound didn't remind me of anything, it was neutral, a piano*." [P4]

However, it could be an annoying sound for other participants, for example:

"*— (Long A4 Note) It is a noisy sound; it didn't let me walk with calmness*." [P2],

On the other hand, the "Wind" sound elicited a feeling of calmness:

"*— (The Wind sound reminds me of) the sea, sometimes I listen to relaxing music and (the Wind sound) reminds me of that a lot*." [P1]

b) "Wind" and "Long A4 Note": Effects on weight, speed, and coordination

The results (TABLE 6.3) show that participants felt faster walking with the "Long A4 Note" than with the "Normal Footsteps" sound. A possible explanation for this is that participants felt also light when walking with the "Long A4 Note" sound. Participants said:

"*— With the piano (Long A4 Note) sound, I felt a bit lighter*." [P1].

With the "Wind" sound, participants also felt that the sound made them walk faster and hurry up, while also evoking a sense of listening to music while walking:

"*— The (Wind) sound is still a noise, but it feels fast, like making you hurry up (to walk)*." [P8],

"*— This (Wind) sound, honestly, I don't know how to describe it - I felt like listening to music.*" [P1]

The survey results also showed that the participants felt more coordinated during the exercise with their natural footsteps ("No Sonification") than with the "Long A4 Note" and “High-Frequency Footsteps” sounds. In relation to this, a participant said that the “Long A4 Note” was not synchronized with the movement:

“— *(Long note A4) It's the most uncoordinated of all because it does not go according with the walk.*” [P7]

c) “Normal” and “High-Frequency footsteps”: Effects on proprioception, weight, agility, speed, and agency

The “Normal Footsteps” let do a higher sense of proprioception than the “High-Frequency footsteps” sound. When participants walked listening to the “Normal Footsteps”, they could know where their feet were, as it can be seen in TABLE 6.3, even if they thought nothing changed in them:

“— *(Normal footstep sound) it reminded me of a bit of a stopwatch with sound, but it did not change anything in me*.” [P4]

“— *(Normal footstep sound) There are some low-pitched steps, also as I was moving, I felt the rhythm of the footsteps*.” [P5].

“— *(Normal Footsteps and High-Frequency footsteps) The sounds I have listened to change my perceptions and speed… (the perception) of feeling my feet; the (real) sound of my feet, I don’t feel it, I just feel the sound that is produced*.” [P1]

In addition, the “High-Frequency footsteps” gave some participants the feeling of having a lighter, more agile, and faster body; however, one participant reported the feeling of walking with high heels, which may involve effort. They said:

“— *It was like a sharper sound. (High-Frequency footsteps) gives the perception of making you move faster; you feel more agile because you feel your body lighter*.” [P5].

“— *I didn’t like the (High-Frequency footsteps) sound; it was like walking in high heels, and I don’t like walking in high heels*.” [P4]

On the contrary, participants commented that the “Normal Footsteps” generate feelings of strong steps and heaviness:

“— *As the hit of the (normal footstep sound) step is strong, it feels heavier*.” [P7].

In relation to the sense of **agency,** the survey results showed that the “Long A4 Note”, “Wind”, and “High-Frequency Footsteps” sounds led to higher feelings of agency than the “No Sonification”; moreover, the participants also noted a higher feeling of agency with the "High-Frequency Footsteps" compared with "Normal Footsteps". They explained that the footstep sounds seemed produced by their steps:

"— *(Normal and High-Frequency footsteps) I feel that a sound is produced when stepping, but I know it is not mine*." [P1]

"— *(Normal Footsteps) I'm walking normal, it's practically like I'm walking without the headphones, even it seems to be a little produced by me*." [P2]

6.2.1.3. Effects of sound conditions for the "Leg lift" exercise

The Friedman test showed a significant difference between sound conditions in arousal ($X^2(4) = 10.58, p = .032$): as shown in TABLE 6.4, participants felt more excited with the "Wave" than with "No Sonification" ($z = -2.156, p = .031, r = .508$) and "note A" ($z = -2.410, P = .016, r = .568$), and with the "Flat" sound than with "note A" ($z = -2.414, p = .016, r = .568$). Agency was also significantly affected by the sound condition ($X^2(4) = 13.62, p = .009$): the feeling of agency was higher with the "No Sonification" than with "Underwater" sound($z = -2.207, p = .027, r = .520$). This difference between "No Sonification" and the other sonifications ("Wave", "Flat", "Underwater", and "Note A") in the Agency's sense, could be because the participants reported that the sensation to produce sound is created only from the prototype.

These results together with those from the "think aloud" task are discussed below.

TABLE 6.4: MEDIAN (RANGE) QUESTIONNAIRE SCORES (7-LEVEL LIKERT-TYPE RESPONSE ITEMS) FOR THE LEG LIFT EXERCISE. * MARKS SIGNIFICANT MEDIAN DIFFERENCES.

Scales	Leg lift exercise				
	No Sonification	**Wave**	**Flat**	**Underwater**	**Note A**
Arousal/Excitation*	3 (1 – 5)	4 (1 – 6)	4 (1 – 6)	2 (1 – 6)	3 (1 – 5)
Movement control	6 (3 – 7)	7 (4 – 7)	6 (2 – 7)	6 (4 – 7)	5 (4 – 7)
Weight	4 (3 – 7)	5 (3 – 7)	4 (2 – 7)	4 (1 – 7)	4 (1 – 7)
Body appearance	4 (1 – 6)	6 (3 – 7)	6 (1 – 7)	4 (2 – 7)	4 (2 – 7)
Cardiorespiratory condition	3 (1 – 6)	3 (1 – 5)	3 (1 – 5)	2.5 (1 – 4)	2 (1 – 5)
Strength	4 (3 – 7)	4 (3 – 6)	4 (3 – 6)	4 (1 – 7)	5 (2 – 6)
Speed	4 (2 – 7)	5 (3 – 6)	4 (3 – 6)	3 (1 – 7)	4 (1 – 6)
Agility	4 (2 – 7)	5 (3 – 6)	5 (3-6)	4 (2 – 7)	4 (1 – 6)
Flexibility	4 (2 – 7)	5 (3 – 7)	4 (3 – 6)	4 (1 – 7)	4 (1 – 7)
Tiredness	4 (1 – 6)	3 (2 – 4)	3 (2 – 4)	4 (1 – 7)	4 (2 – 5)
Difficulty	3 (1 – 5)	5 (3 – 7)	3 (1 – 5)	2 (1 – 6)	2 (1 – 5)
Coordination	6 (4 – 7)	6 (3 – 7)	6 (2 – 7)	6 (2 – 7)	6 (1 – 7)
Fluidity	6 (3 – 7)	6 (4 – 7)	6 (3 – 7)	6 (3 – 7)	5 (2 – 7)
Capability	6 (3 – 7)	6 (3 – 7)	6 (3 – 7)	6 (3 – 7)	6 (3 – 7)
Proprioception	7 (4–7)	6 (2–7)	6 (4–7)	6 (3–7)	6 (2–7)
Agency*	7 (1 – 7)	2 (1 – 7)	3 (1 – 7)	2 (1 – 6)	2 (1 – 7)

a) Effects on emotional state

The survey results showed that participants felt more excited listening to the "Wave" sound than with "No Sonification" and "Note A". However, in terms of qualitative results, participants described the "Wave" sound as interesting:

"— *I found interesting the sounds [Wave] that give you an awareness of your movements.*" [P4]

"— *As it is not a normal sound [Wave] that's why I associate it to Christmas bells*." [P7]

With the "Flat" sound, some participants felt neutral, but some also reported it like a distraction to make the movement:

"— *The last one (Flat sound) is normal, the bells do not add or subtract; the bells are not so good for this (movement)*." [P7].

"— *It seems to me a bit artificial, it (Flat sound) distracted me a little when I performed the exercise*." [P5]

The "Underwater" sound gave a sense of peace:

"— *It feels good to move it, it's like moving (the leg) inside of the water, I have a good feeling with the water*." [P7]

b) "Underwater" sound: effects on weight, ease, fluidity, capability, strength, and proprioception

The qualitative results showed that with the "Underwater" sound participants felt heavier. Despite this feeling, they also reported feeling that the movement was easier, and they had positive comments about this sound:

"— *It feels good but like heavy…Although the leg feels heavy leg because I feel it as being in the water, it feels good (in relation to the movement); it is like moving it in the water, I have a good feeling with the water*." [P7]

In addition, with the water sound there was a sense of performing fluid movements and being capable to perform the movement, while also brought feelings of strength and power. Participants said:

"— *The water is like fluid, like moving in the water is positive. I feel like I can move more my feet (with Underwater).*" [P7]

"— *This sound gave me the feeling that I am hitting a mountain and the mountain collapses; the sound makes me feel a little powerful.*" [P4]

This sense of capability elicited by the water sound could be related to the increase in proprioceptive awareness brought up by this sound, as the sound appears to give awareness of how much to lift the leg and motivate participants to accomplish the movement:

"— *The more you raise the leg the more it produces sounds, so it (the water sound) motivates me because you feel that you are not raising (the leg) enough. I feel that if I don't raise the leg enough then there will not be sound. I must raise (the leg) higher, so I will hear those sounds*." [P5]

c) **"Wave" and "Flat" sound: Effects on speed, weight, flexibility, coordination, agility, proprioception, and control**

During the "Leg lift" exercise, the sound characteristics (i.e., discrete trajectory) of the "Wave" seemed to match well the participants' body movement and helped movement coordination:

"— *(I see this sound) moving according to my movement*." [P2]

"— More in line with my movement." [P2] and "—*It seems to me that coordinate more*." [P5]

"— *(I didn't raise the leg at the maximum position because) this way I could hear different sounds*." [P8]

The "Wave" sound seemed to elicit in participants the feelings of flexibility:

"— *(I felt) a little more flexibility, especially with the last [Wave] sound.*" [P1]

Participants also said that the "Wave" sound pushed them to go faster and made them feel lighter, due to changes in the intensity and frequency of the sound.

"— *When you get up, it (the "Wave" sound) gives you the impulse to do it a little faster.*" [P1].

"— *The more you advance in the movement, the lighter you feel, as it changes from low tones to high tones.*" [P9]

The "Flat" sound also showed its potential to generate feelings of agility and movement awareness:

"— *The (Flat) sound helps me in the perception of lifting the leg, it brings me more movement awareness, (I feel) a little more agile*." [P1].

In addition, both the "Wave" and "Flat" sounds have potential to increase proprioceptive awareness, helping participants to identify the position of their foot.

"— *Last two ("Wave" and "Flat") sounds, which sounded progressively while you moved, they helped to improve body perception*." [P1]

"— *(the "Wave" sound moves according to my foot) When my leg was higher, some notes sounded, and when it was not so raised, other notes sounded*." [P8]

"— *I find interesting the sounds that give you an awareness of your movements*." [P4],

Furthermore, participants commented that the "Flat" sound made them feel in control:

"— *(I felt) in control because I produced the (Flat) sound*." [P3]

6.2.1.4. Effects of sound conditions for the "Thigh stretch" exercise

TABLE 6.5: MEDIAN (RANGE) QUESTIONNAIRE SCORES (7-LEVEL LIKERT) FOR THE "THIGH STRETCH" EXERCISE. * AND ^ RESPECTIVELY MARK SIGNIFICANT AND A TENDENCY TOWARDS SIGNIFICANT MEDIAN DIFFERENCES.

Scales	Thigh stretch				
	No Sonification	**Mechanical**	**Water drops**	**Wind**	**Long A4 Note**
Arousal/Excitation*	4 (1 – 5)	4 (3 – 6)	5 (3 – 6)	3 (2 – 7)	4 (1 – 4)
Movement control	6 (3 – 7)	5 (3 – 6)	4 (3 – 6)	5 (2 – 7)	4 (3 – 6)
Weight	4 (1 – 6)	3 (1 – 6)	4 (2 – 5)	4 (2 – 5)	4 (1 – 5)
Body appearance	5 (3 – 6)	4 (2 – 6)	4 (2 – 6)	5 (2 – 6)	4 (1 – 4)
Cardiorespiratory condition	4 (1 – 5)	4 (1 – 5)	4 (1 – 5)	4 (1 – 6)	4 (1 – 7)
Strength	4 (1 – 5)	4(3 – 6)	4 (3 – 5)	4 (3 – 6)	4 (1 – 6)
Speed*	4 (1 – 5)	4 (1 – 7)	4(1 – 6)	5 (2 – 7)	4 (2 – 7)
Agility	4 (2 – 6)	4 (2 – 7)	4 (3 – 5)	4 (2 – 6)	4 (2 – 7)
Flexibility^	4(2 – 5)	4 (2 – 7)	4 (2 – 5)	4 (4 – 6)	3 (3 – 7)
Tiredness	4 (3 – 5)	4 (3 – 7)	4 (3 – 5)	4 (2 – 6)	4 (3 – 5)
Difficulty	4 (1 – 5)	4 (2 – 4)	4 (1 – 4)	3 (1 – 4)	3 (1 – 7)
Coordination	6 (3 – 7)	6 (2 – 7)	4 (3 – 7)	6 (4 – 7)	4 (3 – 7)
Fluidity^	4 (3 – 7)	6 (3 – 7)	4 (2 – 6)	6 (4 – 7)	5 (2 – 7)
Capability	6 (4 – 7)	6 (4 – 7)	4 (4 – 7)	6 (5 – 7)	6 (4 – 7)
Proprioception	6 (4–7)	6 (4 – 7)	6 (3 – 7)	6 (2–7)	6 (3–7)
Agency	4 (1 – 7)	3 (1 – 7)	3 (1 – 7)	3 (1 – 7)	3 (1 – 6)

The Friedman test showed significant effects of sound condition in arousal ($X^2(4) = 12.518, p = .014$), as shown in TABLE 6.5: participants felt more excited with the "Mechanical" than with the "Long A4 Note" sound ($z = -2.121, p = .034, r = .499$), and with the "Water drops" than with the "Long A4 Note" sound ($z = -2.414, p = .016, r = .568$). There was also a significant effect of sound conditions in speed

($X^2(4) = 14.971, p = .005$): participants felt faster with the "Wind" sound than with the "Water drops" sound ($z = -2.714, p = .007, r = .639$) and "No Sonification" ($z = -2.414, p = .016, r = .568$).

Unless, there was a difference between conditions (*) in flexibility, it was non-significant effect of sound condition ($X^2(4) = 8.34, p = .080$), due to participants feeling more flexible with "Wind" than with "No Sonification" ($z = -2.264, p = .024, r = .533$). There was a difference between sound conditions (*) in fluidity, though non-significant ($X^2(4) = 8.97, p = .062$): people felt their movements were more fluid with "Wind" than with "Water drops"($z = -2.203, p = .028, r = .519$), and with "Water drops" than with "Mechanical" ($z = -1.933, p = .053, r = .445$).

a) Effects on emotional state

The qualitative results showed that participants felt more excited with the "Water drops" sound. This sound-evoked curiosity, leading to exploring the sound characteristics (e.g., discrete trajectory):

"— *(participant's laugh) I was testing if keeping (the stretch) longer, I could hear more a specific sound of the bubbles …. (Did you like it?) yes, I was curious*." [P2]

"— *I felt dumb, I mean I felt calm, maybe because I felt that I stepped on bubbles.*" [P8]

Similarly, the "Mechanical" sound, aroused participants and triggered curiosity, prompting participants to explore the sound characteristics, for example, the discrete trajectory of the sound or the start/end of the sound:

"— *(Did the sound help you?) I was just curious to know if the sound was constant if I stayed with my foot up, but it did not calm me so much."* [P2]

Finally, with the "Wind" sound participants didn't feel calm, but it triggered feelings of speed:

"— *This (Wind) sound called my attention ... it is positive in aspects of speed, but it is not soothing.*" [P8]

b) "Mechanical" and "Water drops" sounds: Effects on movement control, capability, and proprioception

The "Mechanical" sound evoked the sense of being in control of the movement, being more capable, and having more proprioceptive awareness when performing the "thigh stretch". With this sound, participants could identify their movement qualities, for instance, how far they could reach, and the position of their leg, as reflected in their comments below:

"— *Like if I would be a robot*." [P6]

"— *...with the sound that was like 'cracks' (Mechanical sound), ..., I understood how the movement of my leg was, how far my leg reaches and how far it can reach*." [P2]

"— *I wanted to see if the sound continued if I held the leg up*." [P2]

"— *All the sounds that are progressive help in the perception (of the movement)*." [P1]

Thus, the "Mechanical" sonification, being a sound with discrete changes during the movement, could increase participants' proprioceptive awareness. This is also the case for the "Water drops" sound, as participants said:

"— *(Water drops sounds) like bubbles… it just makes me realize that I have raise the foot enough, and if it didn't sound it is because I haven't raised enough*." [P5]

c) "Wind" sound: Effects on speed, ease, and flexibility

With the "Wind" sound participants felt faster. They commented:

"— *This is like The Powerpuff Girls, 'shh' (simulating wind), it's like flying, it's like wind…. Yes (I liked it), it's like the sound makes the things don't go slow, like flying in a cloud*." [P7],

"— *This sound has the positive aspect of speed… it feels like you are going faster*." [P8]

Even if participants considered the "thigh stretch" the most difficult exercise because they needed to stretch their leg back, the "Wind" sound made the exercise feel easier and it also made participants feel more flexible. The participants said:

"— *(the movement) is tiring ...the last sound (Wind sound) helped, it felt like a sea breeze*." [P3]

"— *(it was difficult) because of my flexibility… the sound helped me in that, (feeling) lighter, a little more flexible*." [P2]

6.3. Conclusion

This chapter presented the quantitative and qualitative findings from an exploratory study that aimed to investigate the effects on body and movement feelings, and emotional state of the proposed sonification strategies (Section 5.1.4), implemented through a movement-sound palette and a wearable device when performing PA.

This exploratory study contains a small sample size that does not allow strong quantitative validation for this study, therefore, future research was needed with a big sample size to have a stronger validation, to see in the following chapters (Chapter 7, 8). It is worth mentioning that the statistical analyses performed offer guidance on large effects, although the sample size and effect size are independent of each other, statistical significance depends upon both sample size and effect size [148].

The size of the effect, a.k.a. effect size, is an objective measure of the magnitude of the observed effect, i.e., the effect size will tell how much the sound effect works on the body feelings [149]. It is well known that the bigger the sample the more likely it is to reflect the whole population [149].

Additionally, with a small sample, there is a risk that the results of the survey items may contain outliers of one or two participants, because the smaller the sample, the bigger is the influence of one participant in the results. For example, in this study two participants represent almost the 25% of the participant sample; these participants could report low scores in some of the items assessing body sensations in the survey, and by that have a large influence in the results of the survey that would show overall low effects [142], [143].

Further, this chapter reports the first step taken to investigate the potential of such strategies to address barriers related to PA in physically inactive adults and to inform the future studies in this thesis. The effects of sound condition on the dimensions of change BP and emotional state were identified. Here, this thesis proposes a new design of the movement-sound palettes to enhance the effects in BP and adapt it to the exercise.

6.3.1. Identifying the potential use of sonification for PA

The effects of the proposed movement-sound palette in BP and its potential impacts on PA are studied. The results obtained allowed to identify several potential effects on perceived movement and body qualities of the sonifications designed for each kind of exercise (“step-ups”, “walk”, “leg lift”, and “thigh stretch”). Below the primary results of this study for each movement-sound palette and exercise are presented. TABLE 6.6

presents an overview of the sonifications used in the study, describing their structure, when sonifications are activated, or variations in the sounds.

TABLE 6.6: OVERVIEW OF THE SOUND CHARACTERISTICS IDENTIFIED IN EACH SONIFICATION.

Sound characteristics		Structure		When it sounds			Changes in	
		Continuous	**Discrete**	**Trajectory**	**Start/end**	**Both**	**Frequency**	**Intensity**
Step-ups	Ascending				X		X	
	Can-crush		X		X		X	
Walk	Wind	X		X	X		X	
	Normal Footsteps		X		X			
	High-Frequency Footsteps		X		X			
Leg lift	Wave		X	X			X	
	Underwater	X		X	X			
Thigh stretch	Water drops		X			X		X
	Mechanical		X	X	X		X	X
	Wind	X				X	X	

The sonifications in this chapter followed two sound structures [24], [41]: **Discrete sounds** are divided into intervals or marked by several points that promote sonification, between the start and end position of movement. Therefore, it is possible to provide motion feedback based on the predefined moments by splitting the sound. **Continuous sounds** provide constant feedback in the movement trajectory, which can include feedback in the initial and the target position. For example, the sounds of a continuous flow of water and/or wind.

In addition to the structure of the sound (i.e., continuous vs. discrete sounds), the sonifications could provide feedback throughout the movement (**trajectory**) or only at the starting position and upon reaching the movement goal (**Start/end**), or (**both**) during the whole movement. Moreover, sonification can provide changes in **frequency**, e.g., a high or low frequency in the walking movement, or a real-time change during the trajectory as in Wind; and changes in **intensity** that make a direct relationship to volume, e.g., "Mechanical" indicates a higher intensity once the target of the movement is reached [16], [59].

For the “step-ups**”** exercise, the survey data and thoughts of the participants suggested (TABLE 6.7) that the “Ascending” sound could be used to provide feelings of being positively excited (Strategy 10), and to enhance speed and agility (Strategy 5 and 8); for example, through its quality of “pulling the body” that evoked the sense of being jumping like in a video game. In addition, it appears that the “Ascending” sound affected the sense of balance (Strategy 9), leading to performing more careful steps. On the other hand, the “Can-crush” sound, which participants described as sounding as “cracks”, appears to provide a sense of one’s heartbeat or breath becoming more accelerated (Strategy 3). This sound showed also potential effects on the feelings about the body, e.g., a sense of lightness/heaviness (Strategy 2), facilitating proprioception (i.e., awareness of where their limbs were; Strategy 1), and contributing to the perceived movement’s qualities of agility/speed (Strategy 5).

For the “walk” exercise, the participants highlighted (TABLE 6.7) that the “Long Note A4” sound excited them more than the “No Sonification” (natural footsteps) and “Normal Footsteps” conditions. The sound characteristics of the “Long A4 Note” (i.e., frequency) may be used to influence participants’ perception of their body weight, for example making them feel lighter (Strategy 2). Moreover, the “Long A4 Note” can be used to sonify different parts of the movement to further enhance coordination in cases of loss of movement synchrony (Strategy 10), with some participants reporting as if the sound was adding “noise” to their movements. With the “Wind” sound some participants reported a sense of rushing (Strategy 5), though others described it as a background sound (as listening to music) that helped them to feel in calmness (Strategy 10). For example, participants reported the feeling or need to go faster during the exercise.

In the case of the “Normal Footsteps” sound, this sound created the feeling of walking with stronger steps (TABLE 6.7), which participants related to a body that feels heavier (Strategy 2 and 4). With regards to the “High-Frequency footsteps” participants described that this sound made them feel more agile/faster (Strategy 5), and lighter (Strategy 2).

Lastly both the “Normal Footsteps” and “High-Frequency footsteps” can be used to enhance the awareness of each unit of movement, as both sounds were rated well in terms of the proprioceptive awareness and agency feelings they generated, and participants reported that these sounds produced by their own body helped them to know where their feet were during the “walk” exercise (Strategy 1).

TABLE 6.7: SUMMARY OF THE EFFECTS ON BODY AND MOVEMENT PERCEPTIONS AND EMOTIONAL STATE OF THE DIFFERENT SONIFICATIONS DESIGNED FOR EACH EXERCISE. “+” INCREASE AND “-” DECREASE IN BODY AND MOVEMENT PERCEPTION.

Body and movement perceptions and emotional state	**Step-ups**				**Walk**						**Leg lift**				**Thigh stretch**					
	Ascending		**Can-crush**		**Wind**		**Normal Footsteps**		**High-Frequency Footsteps**		**Wave**		**Underwater**		**Water drops**		**Mechanical**		**Wind**	
	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–
1. proprioception			X						X		X				X		X			
2. body weight			X				X			X	X		X							
3. cardiorespiratory condition			X																	
4. muscle strength and resistance							X						X							
5. speed/agility	X		X		X				X										X	
6. flexibility											X								X	
7. movement progress or achievement															X		X			
8. ease movement start	X												X				X		X	
9. balance/coordination		X									X									
10. emotional factors (joy)	X				X								X		X		X		X	

For the “leg lift” exercise the main effects related to the “Wave”, “Flat”, and “Underwater” sounds (TABLE 6.7). The “Wave” showed that a sound based on musical notes can be played to affect the arousal of participants (Strategy 10), who felt excited with these sounds. Similarly, the “Flat” sound, being a continuous sound and flat in frequency, reminded participants of a bell, and was felt as neutral in terms of arousal. The “Wave” sound, which was described as a piano sound, due to its sound characteristics (i.e., a discrete trajectory, and sound intensity/frequency) prompted participants to go faster (Strategy 5) and clearly help to facilitate continuance in the movement, for example to made them feel more flexible (Strategy 6) and coordinated (Strategy 9). Both the “Wave” and “Flat” sounds had positive effects in feelings of agility (Strategy 5), movement control, proprioception (Strategy 1), and agency, making participants feel as if they were the ones who produced the sound. The “Underwater” sound, for which people reported feeling inside water, can be used for affecting the perceived body weight, to lead to a sense of heaviness (Strategy 2); nonetheless sounds simulating natural sounds, may lead participants to feel calm (Strategy 10) and make movement feel easier (Strategy 8) and more fluid (Strategy 7), increasing the sense of being capable of performing the exercise (Strategy 8). Lastly, the “Underwater” sound seems to have a positive effect on proprioception (Strategy 1), due to participants being able to match the start or end of the sound with their limb position, which prompted them to complete the movement.

For the “thigh stretch” exercise results showed similarities in the effects of the “Water drops” and “Mechanical” sounds, which both have a discrete trajectory (TABLE 6.7). With both sounds, participants felt positively excited (Strategy 10) and reported to enhance proprioception (Strategy 1) and a feeling of movement progress or achievement (Strategy 7). The “Mechanical” sound generated feelings of being in control of the movement (Strategy 1) and can be used for increasing the perceived body capability to perform the exercise (Strategy 4 and 5). Further, the continuous sound of “Wind”, which participants described as making them feel like a sea breeze, led to a sense of calmness and increased the sensation of speed (Strategy 5), flexibility (Strategy 6), and easiness (Strategy 8) of the movement.

The sonifications caused the aforementioned favorable effects on the performance of the exercise. TABLE 6.7 summarizes the effects on perceived movement and body qualities of the various sonifications. The effects of particular sonifications on the PA were grouped, omitting sounds that work as control conditions, see TABLE 6.7. It is worth mentioning that most of the control conditions did not evoke feelings in the participants, except for the “Flat” and “Short A4 Note” sounds in the "walk" exercise which showed several effects. On the one hand, the “Flat” sound had an effect on felt agility, movement control, and proprioception; but it was not considered appropriate for the movement because participants considered the “Flat” sound is not appropriate for the “Leg lift” movement, making participants feel distracted. On the other hand, the “Long A4 Note” sound had an effect on felt weight, making participants feel lighter; but due to its length, it also seemed to confuse participants and reduce their coordination. This will be considered for the redesign of the sonifications.

Results suggest that the sonification strategies implemented in the SoniShoes could generate certain body and movement perceptions in adults while performing various physical exercises. Participants were aware that the metaphorical sonifications employed might help them to perform those different exercises. On the other hand, results showed that the difficulty of the chosen exercises ranged from normal - easy with all the sounds – this may be due to participants having an average general physical fitness level (i.e., they were not physically inactive). Hence, the effects of such sonifications need to be studied in various populations (e.g., physically active and physically inactive adults) and in various types of studies (controlled and in-the-wild studies) in order to refine and assess their potential impact on BP and ultimately in PA. Based on these results, the sounds and device were re-designed to improve the provided sound feedback during the exercises, see details in the next section.

6.3.2. Re-design of the movement-sound palette to enhance the effects in BP and adapt it to the exercise

The quantitative and qualitative results show that the sonification Strategies and the SoniShoes device have the potential to affect bodily feelings related to PA and can be used in PA contexts. However, the sonifications needed a new iteration, in order to allow an investigation of the effects of a particular sound and movement characteristics on the particular body and movement perceptions, as well as to assess the potential accompanying changes in behavior and emotional state. Based on the findings, a re-design is suggested of the movement-sound palette and the SoniShoes that will be used in the subsequent studies.

The second version of the movement-sound palette was designed to assess in more detail a particular strategy or to focus on specific effects. This thesis proposed different sonifications for each exercise, which were based on the previous ones. The aim was to match the sound characteristics with the characteristics of the movement, for instance, movements involving impact on surfaces or movements that have angle changes. Below the new sonifications for each exercise are explained.

For the “step-ups” and “walk” exercises, the sonifications included in the new palette were according to the movement qualities, mainly on sounds that responded to the impact of the foot on the ground but seem to accompanying the swing phase, initially based on [33] for “step-ups” that used the contact of foot in the natural footsteps and change to High- or Low-Frequency versions, as well as in “walk” [17].

In the “Step-ups” exercise, the ascending sound was kept in the new palette, the descending sound, and a constant sound were included. The ascending sound showed strong effects on arousal, speed, and agility, although it could possibly be the reason for leading to a sensation of unbalance and affecting proprioception (Wallace et al., 2004; McGurk & MacDonald, 1976, White et al., 2014). The descending sound was added as a counterpart to the ascending sound [173]. The constant sound (control sound) simulates a “beep” sound without alterations in the direction of the sound [16]. The control sound is provided to assess the idea that the effects are produced by listening to a sound.

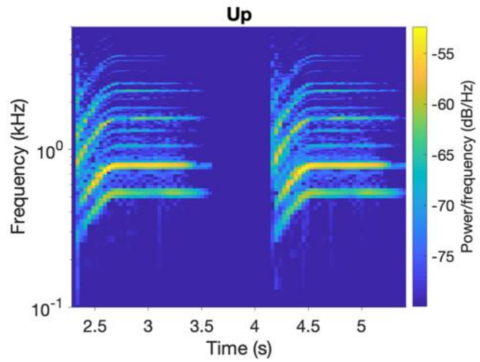
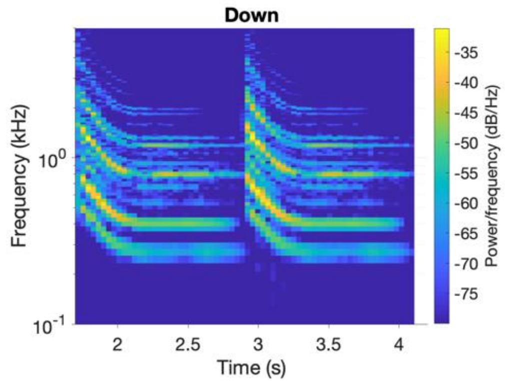
For the “walk” exercise, the sonifications included in the new palette were the “Wind” and “Can-crush” sonifications, and two control sounds: “Control Wind” and “Control Can”. While the “Wind” sound accompanying the “thigh stretch” in the exploratory study did not show strong effects, it was decided to map its sound characteristics with different movement characteristics: the sound in this new version is still a continuous sound but it increases its frequency and intensity according to the pressure level of the feet over the ground. The “Can-crush” is composed of discrete sounds with several pitches (which participants referred to as “cracks”). This sonification was kept to further study the effects obtained in the exploratory study, such as the effects on perceived weight, agility, cardiorespiratory condition, speed, and proprioception.

The “leg lift” and “thigh stretch” sonifications focused on angle changes and movement acceleration. For “leg lift”, there were five sound conditions: “Water”, “Wind”, “Ascending-Descending”, “Flat” (Control) sound, and “No Sonification”. The “Water” sound differed from the ones used in the exploratory study, and combined characteristics of the “Underwater” and “Water drop” sounds: this new sound is a continuous sound that is formed by an “Underwater” sound and two splash sounds, one splash at the beginning and one splash at the end of the movement, as in (Singh et al., 2016) with water-like sound with splash that enhances proprioception. The “Wind” sound is also a continuous sound, as in the “walk” exercise, but it was adapted to match the changes in frequency and intensity with movement angles and accelerations, marking the end of the movement with a High-Frequency sound. The “Ascending-descending” sonification, combines the “Ascending” and “Descending” sounds and it is triggered by angles changes at the start and end position of the movement: at the start of the "leg lift" movement, the "Ascending" sound is triggered, while the "Descending" sound is activated at the end of the "leg lift" when the leg starts descending. This sound was included to further study the effects shown in the exploratory study, like effects on felt capability, and movement fluidity.

For the "thigh stretch", the same sounds included in the "leg lift" sonifications were kept except for the "Ascending-Descending" sound which was substituted by the "Mechanical sound" - a discrete sound with gradual changes – as these sounds characteristics could better support this exercise as the angle movement in "thigh stretch" is longer than in the "leg lift" because there is more distance to produce the "Mechanical sound". This sound showed effects on perceived movement control, progress, proprioception, and capability in the exploratory study.

The tables below show in detail the characteristics of each movement and how they were matched to the sound characteristics (e.g., start/end and trajectory of the movement). The sounds used in the palette are based on pre-recorded samples of sounds that are modified in real-time according to the sensor inputs, with the exception of the "Wind" sound, which consists of pink noise. See details for each palette and movement in the tables below: "step-ups" (TABLE 6.8), "leg lift" (TABLE 6.9) "walk" (TABLE 6.10), and "thigh stretch" (TABLE 6.11).

TABLE 6.8: DESCRIPTION OF THE IMPLEMENTED SONIFIED EXERCISE FOR THE “STEPS-UP” EXERCISE, NS = NO SONIFICATION.

Type of sonification	**Sounds**	**Description**	**Toe-off**	**Leg up**	**Foot Strike**	**Toe off**	**Leg down**	**Foot Strike**	**Sensor**	**Spectrogram**
Up sound	Boing sound	A “beep” sound modified to give an effect of “boing” sound - time for reaching 0.8 seconds.	“Spring” sound when body part is lifting.	NS	NS	“Spring” sound.	NS	NS	Back FSR (Heel)	
Down sound	Boing inverse	A “beep” sound with a descending effect - time for reaching 0.8 seconds.	A reverse “Spring” sound when body part is lifting.	NS	NS	A reverse “Spring” sound.	NS	NS	Back FSR (Heel)	

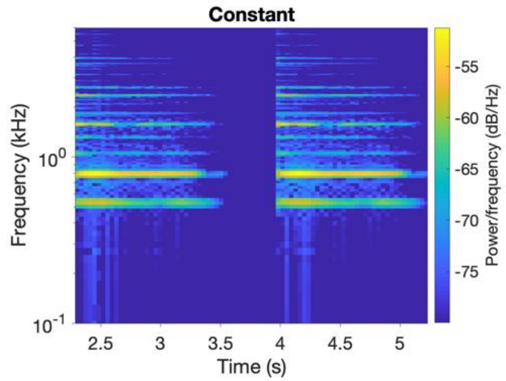
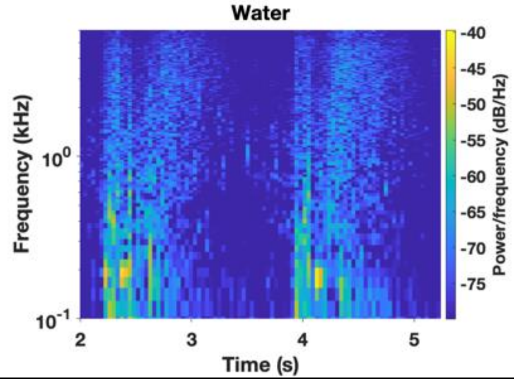
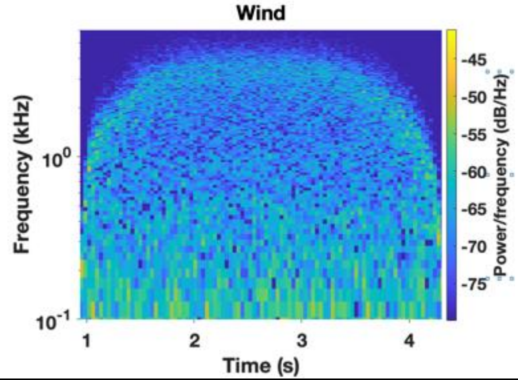
Constant	Beep	A flat sound from a "beep" sound - time for reaching 0.8 seconds.	A tone when body part is lifting.	NS	NS	A tone	NS	NS	Back FSR (Heel)	

TABLE 6.9: DESCRIPTION OF THE IMPLEMENTED SONIFIED EXERCISE FOR THE “LEG LIFT” EXERCISE, NS = NO SONIFICATION.

Type of sonification	**Sounds**	**Description**	**Start and end position (0° when the foot is on the floor)**	**Trajectory**			**Sensor**	**Spectrogram**
				Up (Ascending 1° - 90°)	**Maximum position (90° approx.)**	**Down (Descending 90° - 1°)**		
Continuous with a cue at the beginning and ending of the movement.	Water	Underwater and splash sound.	Underwater sound when leg is static.	After passing 10% in the range of movement (13°-15° approx. over the ground), a splash sound arises.	Approx. 90° - NS.	Splash sound when going down in the 90% in the movement range.	Angle	
Continuous	Wind	Wind sound replicated with pink noise.	Start the movement with a frequency of 220 Hz.	Progressive increase in wind (pink noise) frequency.	Wind keeps sounding.	Progressive decrease in frequency.	Angle	

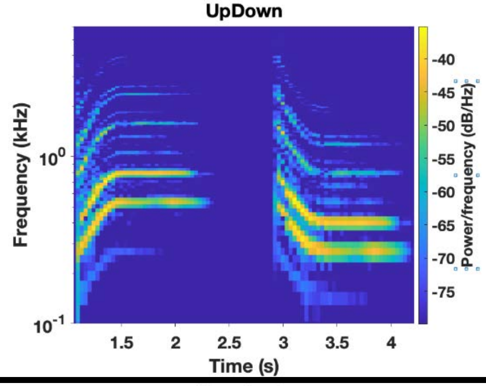
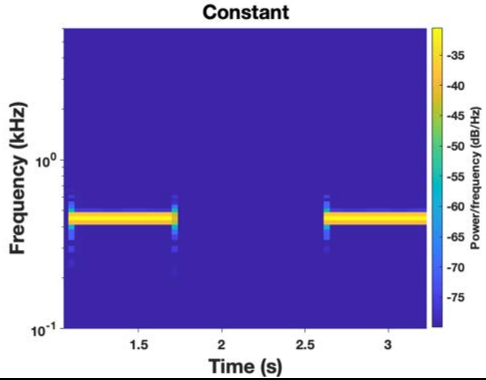
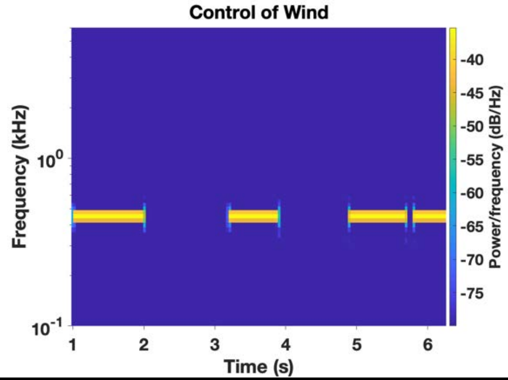
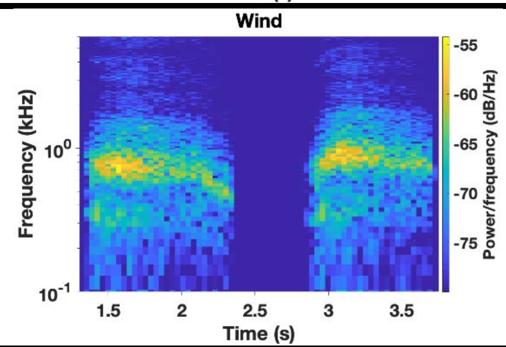
Type of sonification	Sounds	Description	Start and end position (0° when the foot is on the floor)	Trajectory			Sensor	Spectrogram
				Up (Ascending 1° - 90°)	Maximum position (90° approx.)	Down (Descending 90° - 1°)		
Without trajectory	Up-down	“Boing” up and down sounds.	NS	Spring sound.	NS	Reverse spring sound.	Angle	
Flat continuous sound	Control	440 Hz of frequency.	440 Hz of frequency.	Tone	NS	Tone	Angle	

TABLE 6.10: DESCRIPTION OF THE IMPLEMENTED SONIFIED EXERCISE FOR THE "WALK" EXERCISE, NS = NO SONIFICATION.

Type of sonification	Sounds	Description	Heel Strike	Mid-Phase	Toe Strike	Toe off	Leg up	Leg down	Sensor	Spectrogram
Continuous	Control Wind	A constant sound with a frequency of 440Hz and same duration as Wind sound.	NS	NS	A constant sound with a frequency of 440Hz	NS	NS	NS	FSR in front (toe)	
Continuous	Wind	Wind sound replicated with pink noise.	NS	NS	Increase sound frequency	NS	NS	NS	FSR in front (toe)	

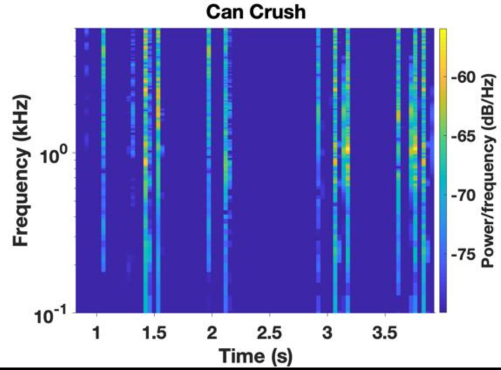
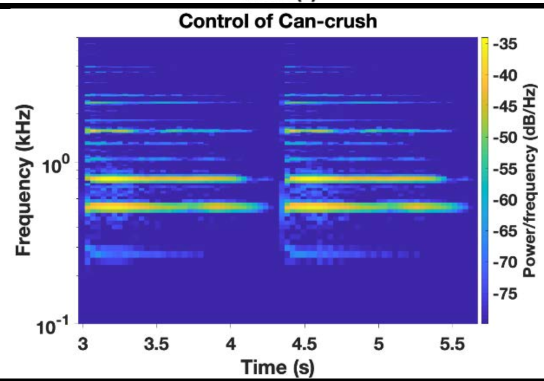
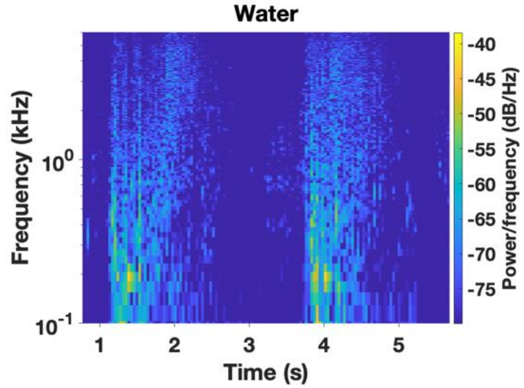
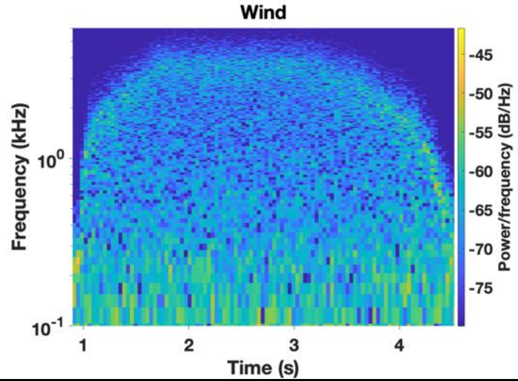
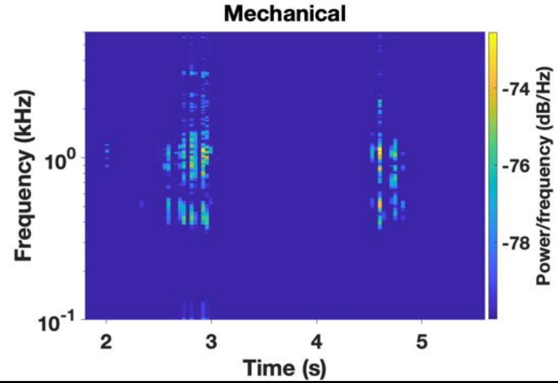
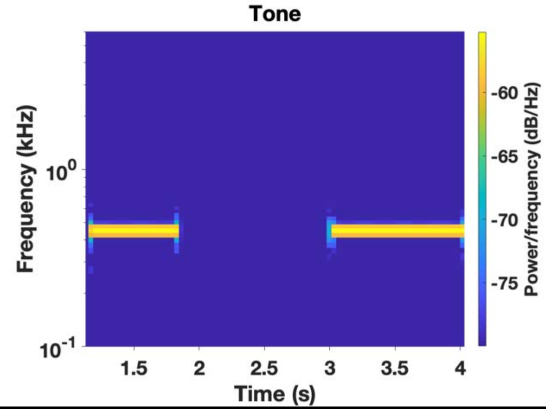
Type of sonification	Sounds	Description	Heel Strike	Mid-Phase	Toe Strike	Toe off	Leg up	Leg down	Sensor	Spectrogram
Continuous made of concatenated discrete sounds	Can-crush (Crashed aluminum coke can)	A crush can sound like aluminum can.	NS	NS	Aluminum Can-crush over the floor	NS	NS	NS	FSR in front (toe)	
Flat continuous sound	Control Can	A constant sound like a “beep”.	NS	NS	A constant sound	NS	NS	NS	FSR in front (toe)	

TABLE 6.11: DESCRIPTION OF THE IMPLEMENTED SONIFIED EXERCISE FOR "THIGH STRETCH" EXERCISE, NS = NO SONIFICATION.

Type of sonification	Sounds	Description	Start and end position (Between 0° - 5°)	Trajectory: Up (Ascending 6° - 99°)	Trajectory: Hold (Keep between 100° - 115°)	Trajectory: Down (Descending 99° - 6°)	Sensor	Spectrogram
Continuous with a cue at the beginning and ending of the movement	Water	Underwater and splash sound.	Underwater sound when the leg is static.	After passing 10% in the range of movement (13°-15° approx. over the ground), a splash sound arises.	NS	Splash sound when going down in the 90% in the movement range.	Angle	
Continuous	Wind	Wind sound replicated with pink noise.	Start the movement with a frequency of 220 Hz. Spectral centroid = from 460.7 to 1129 Hz.	Progressive increase in wind (pink noise) frequency., Spectral centroid = between 1789 & 3269 Hz.	The wind keeps sounding at a frequency of 3520 Hz. Spectral centroid = from 3379Hz.	Progressive decrease in frequency. Spectral centroid = from 3210 to 1685 Hz.	Angle	

Type of sonification	Sounds	Description	Start and end position (Between 0° - 5°)	Trajectory			Sensor	Spectrogram
				Up (Ascending 6° - 99°)	Hold (Keep between 100° - 115°)	Down (Descending 99° - 6°)		
Continuous with a sense of being discrete	Mechanical	Mechanical sound like gears moving.	NS	Gear sounds start to sound, after passing 10% (13°-15° approx. over the ground) in the range of movement.	NS	Gear's sound.	Angle	
Continuous	Tone	440 Hz of frequency.	440 Hz of frequency.	The frequency of 440 Hz without changes.	NS	The frequency of 440 Hz without changes.	Angle	

6.4. Chapter summary

In this section, it is summarized the effects of the various sonifications on the perception of the body when doing PA and the appropriateness of the designed movement-sound palette for the chosen exercises. The effects on the perceived body and movement qualities are related to the various sonification strategies followed to affect them (see TABLE 6.7 for a summary). Lastly, a re-design of the movement-sound palette based on the findings is proposed (TABLE 6.8, TABLE 6.9, TABLE 6.10, TABLE 6.11).

The next chapter will present three studies that aimed to investigate how a new movement-sound palette could be used to impact one's own BP, movement behavior, and emotional state, in order to address psychological barriers to PA. Those studies helped to validate the results on the effects of the movement-sound palette suggested by the exploratory study presented in this chapter. In Chapter 7, a refined SoniShoes device is presented, with new hardware and settings. A new version of the device called SoniBand is introduced, this device, based on angle changes, can be used to explore the effects of the sounds accompanying the movement of people's upper limbs ("side arm exercise"), or lower limbs (e.g., "leg lift" and "thigh stretch").

7. QUANTITATIVE STUDIES

The previous chapter conducted an exploratory study to understand the potential effects on BP and emotional state of various movement-sound mappings designed to address various psychological barriers to PA. This chapter present three quantitative studies designed and conducted as controlled lab studies which aimed to investigate the effects of movement sonification on BP, emotional state, and movement behavior, see TABLE 7.1. These effects may in turn facilitate PA by addressing different barriers related to BP. Each study focused on different exercises (“walk”, “thigh stretch”, “leg lift”, and “side arm raise”), which each helps increasing different aspects of body fitness (respectively, general body fitness/toning, strength, cardiorespiratory condition, strength) and brings different BPs into focus. Further, these studies aimed to address the third research question (**RQ3**: *“How can we integrate movement sonification in wearable technology for PA and evaluate it in adults?”)*

TABLE 7.1: SUMMARY OF THE THREE STUDIES PRESENTED IN THIS CHAPTER WITH THE TYPE OF EXERCISES BELONGING TO EACH STUDY, THE PROTOTYPE AND SONIFICATIONS IMPLEMENTED FOR EACH MOVEMENT, AND THE PERCEPTION OF THE BODY AND THE MOVEMENT EXPECTED TO BE IMPACTED.

Study	Type of exercise	Prototype	Sonifications	Targeted BP aspect
Study 1	Walk	SoniShoes	Wind, Control Wind, Can-crush, Control Can, No Sonification (control)	Agility, cardiorespiratory condition, coordination
	Thigh stretch		Water, Wind, Mechanical, Tone (control), No Sonification	Flexibility
Study 2	Leg lift	SoniShoes	Water, Wind, Up, Continuous (control), No Sonification (control).	Strength
Study 3	Side arm raise	SoniBand (desktop version) & Go-with-the-Flow-Moves@HOME	Experiment 1: Tone_up, Tone_down, Tone_constant,	Proprioception
			Experiment 2: Tone_up, Tone_down, Musical_up, Musical_ down	
			Experiment 3: Musical_up_Low_pitch, Musical_down_Low_pitch, Musical_up_High_pitch, Musical_down_High_ pitch.	

As the studies reported here were conducted in collaboration with other researchers in the framework of a research project, this thesis contributions to each of the studies are clarified.

7.1. Study 1: Effects of movement sonification during "Walk" and "Thigh stretch"

Following the findings of the exploratory study, controlled study was conducted, divided into two exercises: "walk" and "thigh stretch". In both exercises, the aim was to analyze whether movement sonification could change body feelings, emotional state, and movement behavior during PA. Both exercises involve different body capabilities and thus bring different BPs into focus. The "walk" exercise is mainly focused on the sound effects on feelings related to the cardiorespiratory condition, as well as agility and coordination, during PA; while the "thigh stretch" exercise focused on the sound effects on feelings related to body flexibility.

7.1.1. Author contributions and related publication

In this study, I was responsible for the recruitment, acquisition, and analysis of the data. I contributed to the conception and design of the work; the development of the sonification mappings and the software and hardware for such movement sonification and data acquisition; and the interpretation and writing of the study with supervision from other senior researchers from the research team.

Part of these studies have been published in the form of a conference paper. The full reference of the paper is:

Ley-Flores, J., Bevilacqua, F., Bianchi-Berthouze, N., & Tajadura-Jiménez, A. (2019). *Altering body perception and emotion in physically inactive people through movement sonification*. Proceedings of the 2019 International Conference on Affective Computing and Intelligent Interaction (ACII), 3rd-6th September 2019, Cambridge, UK. DOI: https://doi.org/10.1109/ACII.2019.8925432

7.1.2. Methods

7.1.2.1. Participants and setting

A controlled study was conducted with twenty-six participants (M_{age} = 22.08, SD_{age} = 5.19, Range= 18 – 44; n=15 females, 11 male). The study was approved by the Ethics Committee of Universidad Carlos III de Madrid (see Appendix D).

Physical inactive adults participated in the study. They were selected in a pre-screening using the International Physical Activity Questionnaire (IPAQ, [67]; Spanish version validated [144]) and taking also into account the number of hours per week they spent performing sport activities. From 246 people, 26 were selected, four of them with a low PA level (< 600 MET/week) and twenty-two with moderate-low PA level (from 1500 to 3000 METS/week); they all performed less than 2 hours of sporting activities per week [150].

The study was conducted in a quiet classroom of the University, with a length of 9.3 meters; this dimension was considered in order to provide enough space and time for the participants to walk a straight distance during the "Walk" exercise (see Procedure below).

Before starting the study, participants were informed about the aims and tasks of the study through an information and consent form that they signed. Then, they were asked to fill out the International Fitness Scale (IFiS) to characterize the participant sample in terms of their self-perception of their physical condition [45], [46]. IFiS results are reported through the median (range) score, on a scale from 1 (very poor) to 5 (very good) perceived condition. Results showed that participants felt that their general physical fitness, muscular strength, and speed/agility were "average", with these three scales showing a median score of 3 out of 5 (range: 1-4), but they felt that had a "poor" cardiorespiratory fitness condition and flexibility, as the median score for these scales was, respectively, 2 out of 5 (range: 1-4) and 2.5 out of 5 (range: 1-5). This confirms that participants were appropriate to the focus of the study, which was to change BPs related to cardiorespiratory endurance, coordination, and flexibility during PA.

After filling out the IFiS, participants put on the SoniShoes and were instructed in the exercises of "walk" and "thigh stretch".

Exercises

The "walk" (structured according to the toe-heel strike on the floor) and "thigh stretch" (structured according to the start and end position, and movement trajectory) exercises, see TABLE 7.2. The structure allows determining the limit of the movement for the correct application of the sounds. For "walk", participants were asked to walk normally for one minute. For "thigh stretch", participants were asked to raise their leg back once to allow the shoes to be calibrated. Participants raised their left foot until it was as close to the thigh as the participant could achieve, then they were asked to return the foot to the floor; the minimum (foot on the floor) and maximum (leg raised closer to thigh) positions were recorded. This constitutes one repetition and participants performed five repetitions per sound condition.

TABLE 7.2: DESCRIPTION OF THE “WALK” AND “THIGH STRETCH” EXERCISES.

Exercises	Description	Example	
		Trajectory ------	
		Start position •	Objective ➤
Walk	**Initial Position:** Stand with your legs shoulder width apart.		
	Trajectory: Start walking with the right foot. (Stance phase). The right heel strikes on the floor; press the right foot completely on the floor until the right toe separates from the floor (toe-off event). (Swing phase) Move the right leg in the air until the heel strikes again on the floor. Same for the left leg.		
	Objective (walking): One gait cycle is completed each time the right heel strikes the floor after the swing phase.		
Thigh stretch	**Initial Position:** Stand with the no dominant arm, with the possibility of resting the hand on a chair or wall.		
	Trajectory: Stand on one leg, raise the foot of the other leg to flex it and keep it up.		
	Objective (stretching): Hold the foot up for 1-5 seconds, keep the knee pointing down and pull the foot up with slight pressure. **After reaching the objective:** Release the foot and lower it to return to the initial position.		

7.1.2.2. Apparatus and stimuli

a) SoniShoes: desktop version

The SoniShoes prototype (see FIGURE 7.1) consists of two sandals with sensors integrated; in each sandal, there is a wireless emitter microcontroller called BITalino R-IoT, embedding an Inertial Motion Unit (9 axis, IMU) and connected to two Force Sensitive Resistors (FSR) placed under an insole. Moreover, the prototype is connected via Wi-Fi to the software Max/MSP which allows to sonify the movement detected through the FSR and IMU sensors (for more details see Section 5.2.2).

FIGURE 7.1: (LEFT) THE SONISHOES OF THE RIGHT FOOT AND A BAND ATTACHED TO THE ANKLE; (CENTER) THE BAG OF THE BAND HAVE A BATTERY AND R-IOT; (RIGHT) BACK FORCE-SENSITIVE RESISTOR (FSR) IN THE SANDAL.

b) "Walk": sound stimuli

As a result of the exploratory study (Chapter 6) with a "walk" experiment, four sound conditions were used. Two of the stimuli were environmental sounds: "Wind" sound and "Can-crush" sound, with their respective control sound, "Control Wind" and "Control Can". It can be assumed that these sounds should evoke known natural phenomena or actions, like the sound of an aluminum can being crushed. The "Wind" sound consists of pink noise that increases or decreases in frequency (from 220 to 3520 Hz) in response to the FSR value [24], [126]. The "Can-crush" sound was recorded by pressing a metal can against the ground [117]. Both, the "Control Wind" and "Control Can" sounds are pure tonal sounds that have the same duration as their respective naturalistic sound (i.e., "Wind" and "Can-crush") and a frequency of 440 Hz [41], [59], [151], see the TABLE 7.3). Both sonifications are intended to be used as control stimuli and there is no metaphor associated. Therefore, these "control" sounds were used with the aim of verifying that it is not simply hearing a sound while performing the movement that evokes the effect.

c) "Thigh stretch": sound stimuli

For thigh stretch, as well as in the "walk" experiment four sound stimuli were designed as result of the exploratory study: "Wind", "Water", "Mechanical", and "Tone". As in "Walk", the "Wind" sound consists of pink noise that increases or decreases in frequency (from 220 to 3520 Hz) in response to the angle changes [24], [126]. The "Water" sound replicates the sense of continuous water sound and a respective splash at start and end position [41], [112]. The "Mechanical" sound simulates a gears' sound that sounds during the trajectory of the movement [25], [141], see TABLE 7.3). The "Tone" consists of a constant and pure sound that sounds continuously from the start to the end of the movement. As for the "Walk exercise" the "Tone" sound was used as a "control" sound to verify the possible effect of simply hearing a sound while performing the thigh stretch exercise.

Lastly, in both exercises, the "No Sonification" condition was used to compare the effects with a stimulus and without a stimulus.

7.1.2.3. Measures

a) Questionnaire data:

A questionnaire was used divided into two sections: emotional state and body feelings. The emotional state questionnaire contained 2 items (9-point Likert-type), which correspond to the valence/happiness and arousal/excitation scales of the Self-Assessment Manikin (SAM) [152]. The body feelings questionnaire contained 17 items (7-point Likert-type) (see Appendix E and Appendix F). The reliability of each dimension was measured through Cronbach's Alpha, $\alpha = 0.646$, This questionnaire allowed participants to report their own BPs during each experimental sound condition [17], concretely:

- The first 7 items were related to the general perception of the body. They start with the sentence: "As I was doing the exercise, I felt…" and are followed by 7-point bipolar scales ranging between:
  - light (1) – heavy (7), **Weight**
  - weak (1) – strong (7), **Strength**
  - slow (1) – quick (7), **Speed**
  - not agile (1) – agile (7), **Agility**
  - inflexible (1) – flexible (7), **Flexibility**
  - not tired (1) – tired (7), **Tiredness**
  - my heart/breath did not accelerate (1) –accelerated (7), **Heart/Breath accelerated**
- The next 7 items were related to movement of the body, where three items open with "I felt my movements were", then they are followed by 7–point bipolar scales ranging between:
  - easy (1) – difficult (7), **Difficulty**
  - uncoordinated (1) – coordinated (7), **Coordination**
  - not fluid (1) – fluid (7), **Fluidity**
- One item was "I felt I was… of my movements" and participants choose among 7 points ranging between:
  - not in control (1) – control (7), **Movement control**
- in the other three items participants choose among 7 points ranging between:

- I felt… capable (1) – incapable (7) of completing the exercise, **Capability**
- I could not tell (1) – could tell (7) exactly where my foot was, **Proprioception**
- I felt my muscle was… not working at all (1) – working hard (7), **Building muscles**,

- Three last items were related to the sounds participants heard. Participants choose among7 points ranging between:
  - not produced (1) – produced by me (7), **Agency**
  - did not motivate (1) – motivated (7) me to do the exercise, **Motivation**
  - uncomfortable (1) – comfortable (7), **Comfort**

b) Behavioral data:

Furthermore, the study was conducted with behavior data being gathered via the IMU sensors in the BITalino R-IoT and the FSR sensors attached to the ankles and sandal insoles, see FIGURE 7.1. For the "walk" exercise the acquired data were the maximum and mean heel and toe pressure applied on the ground; heel-ground and toe-ground contact times (i.e., time that the heel or toe is in contact with the ground) and stance time (i.e., the period between the foot first touch on the ground and the moment the foot leaves the ground). For both exercises, "walk" and "thigh stretch", the following movement parameters were recorded via the gyroscope to compute: maximum angle (peak angle), mean angle, time from minimum to maximum position (time up), time from maximum to minimum position (time down), velocity from minimum to maximum position (velocity up), velocity from maximum to minimum position (velocity down). Moreover, the data were captured via the accelerometers to calculate maximum acceleration from minimum to maximum position (max acc up), and maximum acceleration from maximum to minimum position (max acc down). In terms of performance, for "walk", when ground contact times are shorter and acceleration is larger, that indicates a more active walking style; or a higher pressure applied on the ground could indicate higher strength applied. Meanwhile, for "leg-lift", higher angle indicates better performance; or a slow velocity indicates more strength applied during the movement.

c) Physiological data:

Further, to complement the data collection, the physiological signals were recorded on the cloud using a wrist band (Empatica bracelet[7]) attached to the left hand of the participant. This band incorporates

[7] https://www.empatica.com/research/e4/

sensors measuring Electrodermal Activity (EDA) also called galvanic skin response, and Blood Volume Pulse (BVP). EDA is measured in microSiemens (μS). The BVP does not have a unit of measurement[8] because it is a signal that combines two measures, inter-beat-interval and heart rate. EDA and BVP measured whether participants were physiological aroused during each sound condition [153]–[156]. The physiological data were recorded continuously throughout "walk" and "thigh stretch" exercises and processed using MATLAB software.

7.1.2.4. Experimental procedure

A within-subjects experimental design which included "walk" and "thigh stretch" exercises with their experimental sound conditions were followed. For "walk", participants performed the exercise listening to either "Wind", "Control Wind", "Can-crush" or "Control Can" sounds. For "thigh stretch", participants listened to either "Wind", "Water", "Mechanical", or "Tone" sounds. For both exercises, "No Sonification" was added as a control condition, see details in TABLE 7.3. The order of the conditions was randomized to avoid the bias and anchor effects of the initial value.

First, participants performed the "walk" experiment. For each sound condition, they walked for one minute while listening to the sounds their movement produced and while behavioral and physiological data were acquired. After they finished the one-minute walk, with the current sound condition, participants filled out the questionnaire that measured their emotional state (arousal, valence) and body feelings (weight, strength, speed, agility, flexibility, tiredness, heart/breath accelerated, difficulty, coordination, fluidity, control, capability, proprioception, building muscles, agency, motivation, comfort). This procedure was repeated for each sound condition. Next, they performed the "thigh stretch" experiment.

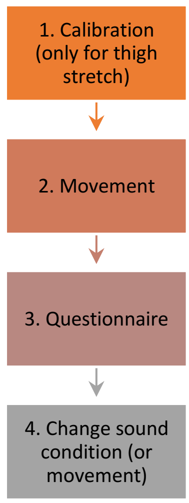
In the case of the "thigh stretch", the participants started with the calibration step, which allowed to store the information of the leg in two positions. For the start position (or minimum position), the participants extended the leg and placed the foot on the ground. For the end position (or maximum position), the participants were still standing, bent the knee, and hold the leg while the angle reached was stored.

Next, to perform the "thigh stretch" participants lifted back their right foot to stretch the thigh, they held it up for 1 second with their right hand and then they released it. Participants could lean their left

[8] https://support.empatica.com/hc/en-us/articles/360029719792-E4-data-BVP-expected-signal

hand on the wall to keep stability. They were asked to repeat the thigh stretch 5 times for each sound condition. As for the "walking" experiment, behavioral and physiological data were acquired during the movement, and participants filled out the questionnaire after each sound condition. The full experiment lasted on average 60 minutes.

TABLE 7.3: EXPERIMENTAL MOVEMENTS, CONDITIONS, NUMBER OF REPETITIONS, AND GRAPHICAL REPRESENTATION OF EXPERIMENTAL PROCEDURE.

Movements	**Condition**	**Time/ repetitions**	**Procedure**
Walk	No Sonification (control)	One minute	
	Wind		
	Control Wind		
	Can-crush		
	Control Can		
Thigh stretch	No Sonification (control)	5 repetitions (Hold 1 second and release)	
	Water		
	Wind		
	Mechanical		
	Tone (control)		

In both exercises, the participants did not wear headphones with the "No Sonification" condition, so that they listened to their own natural walking sounds produced during "walk", or their natural sounds produced with the "thigh stretch" exercise.

7.1.2.5. Data Analysis

For the analysis of the questionnaire data, in the case of the "walk" exercise "Wind" vs "Control Wind" and "Can-crush" vs "Control Can" were compared, that is, each sound condition with its control sound condition. All sound conditions were also compared to the "No Sonification" condition. In the case of the "thigh stretch" exercise, all conditions were compared between each other. The statistical literature indicates that for questionnaires with Likert scales it is appropriate to employ non-parametric tests [146]. Non-parametric Wilcoxon tests were used involving pairwise comparisons to analyze the effects of the different sound conditions on body and emotion feelings. The significance level for all statistical tests was fixed at $p < .05$, and complemented with the corresponding effect size statistic, $r = Z/\sqrt{N}$ [147] (large effect is .5, a medium effect is .3, and a small effect is .1). Statistical analysis was performed by using SPSS Statistics 26.0 Data Analysis.

In the case of the movement data, first Shapiro-Wilk tests were conducted to assess normality of the data. As data were normal, parametric analyses were conducted. In particular, for each exercise I conducted separate repeated measures analysis of variance (ANOVA) with the data for each of the movement parameters (e.g., maximum, and mean FSR, peak angle, time, velocity, and acceleration). The ANOVAs included all five conditions conducted for the exercise. After the ANOVA analysis, paired t-test comparisons were followed for the significant effects $p > .05$ obtained, which were corrected for multiple comparisons with LSD by using SPSS Statistics 26. Here, the significant level was complemented with the corresponding effect size statistic: Partial eta-square ($\eta 2$) directly obtained from the statistical program (large effect is .14, a medium effect is .06, and a small effect is .01 or higher) and computed the corresponding effect size with Cohen's d for paired sample t-tests by using the formula: $d = Mean/SD$, (large effect is .8, a medium effect is .5, and a small effect is .2). The gathered data from the walking experiment showed one of the foot sensors stopped working for 12 participants, therefore the collected data were used of those whose foot sensor functioned well and computed the mean in both feet for all other participants.

Lastly, for the physiological data (EDA and BVP) analysis, the Shapiro-Wilk tests for EDA and BVP data resulted to be non-normal. Then, for both movements I followed the same analysis as for the questionnaire data: for walking, non-parametric Wilcoxon tests were followed (by using SPSS Statistics 26.0) to compare the physiological data of each sound condition with their control and "No Sonification" condition. For thigh stretch movement, all the sound conditions were compared between each other. The significance level was fixed as $p < .05$, with the effect size statistic r, calculated with the formula $r = Z/\sqrt{N}$ [147] (large effect is .5, a medium effect is .3, and a small effect is .1).

7.1.3. Results

This section reports the results on the effects of sound on the three dimensions mentioned above: emotional state, BP and movement behavior. For emotional state, this section reports together the valence and arousal data obtained from the questionnaire and the physiological results on participants arousal. For BP, this section reports the results on bodily feelings obtained from the remaining questionnaire items. For movement behavior, this section reports the results obtained from the sensor data.

7.1.3.1. Effects of sound condition during "walk" exercise

TABLE 7.4: MEDIAN (RANGE) FOR EMOTION AND BODY FEELINGS QUESTIONNAIRE ITEMS SHOWING SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS FOR THE WALKING EXERCISE. QUESTIONNAIRE ITEMS WERE 7-POINT LIKERT-TYPE ITEMS, EXCEPT FOR VALENCE AND AROUSAL WHICH WERE 9-POINT LIKERT-TYPE ITEMS.

Scales	Sound conditions during the "walk" exercise				
	Can-crush	**Control Can**	**Wind**	**Control Wind**	**No Sonification**
Valence/Happiness	6 (3 – 9)	6.5 (3 – 9)	6 (3 – 9)	5 (1 – 9)	6.5 (5 – 9)
Arousal/Excitation	5.5 (1 – 9)	5 (1 – 8)	4 (1 – 8)	5 (1 – 8)	4 (2 – 7)
Flexibility	4 (1 – 7)	5 (1 – 7)	4.5 (1 – 7)	4 (1 – 7)	4 (1 – 7)
Tiredness	3 (1 – 6)	2.5 (1 – 5)	2 (1 – 5)	3 (1 – 5)	3 (1 – 5)
Heart/Breath Accelerated	4 (1 – 6)	4 (1 – 6)	4 (1 – 7)	4 (1 – 6)	4 (1 – 7)
Movement control	6 (2 – 7)	6 (1 – 7)	6 (2 – 7)	6 (3 – 7)	6 (3 – 7)
Proprioception	7 (3 – 7)	7 (3 – 7)	7 (2 – 7)	7 (2 – 7)	7 (2 – 7)
Agency	5 (1 – 7)	6 (1 – 7)	6.5 (1 – 7)	2.5 (1 – 7)	–
Comfort	4 (1 – 7)	4 (1 – 7)	4 (1 – 7)	2 (1 – 4)	–

a) Effects of sound on emotional state

The first two items in TABLE 7.4, show the results related to reported happiness and excitation. These self-reports were complemented with physiological EDA and BVP data. Comparing "Wind" and "No Sonification", "Wind" made participants feel more excited$(z = -2.094, p = .036, r = .290)$, although less happy $(z = -2.138, p = .033, r = .296)$ than with the "No Sonification" condition. Comparing "Control Wind" and "No Sonification" conditions, participants felt less happy $(z = -3.07, p = .002, r = 0.425)$ in "Control Wind". Besides, the "Control Can" condition evoked in participants the sense of being more excited $(z = -2.309, p = .021, r = .320)$ than with "No Sonification".

For physiological data (EDA and BVP), the data showed a significant effect of sound condition only in the EDA data ($X^2(4) = 13.108, p = .011$). It was found that during the "Control Can" condition individuals showed a higher level of electrodermal activity than with the "Can-crush" sound ($z = -3.695, p < .001, r = .512$) (see FIGURE 7.2). There were no significant effects of sound condition in BVP ($X^2(4) = 2.923, p = .571$).

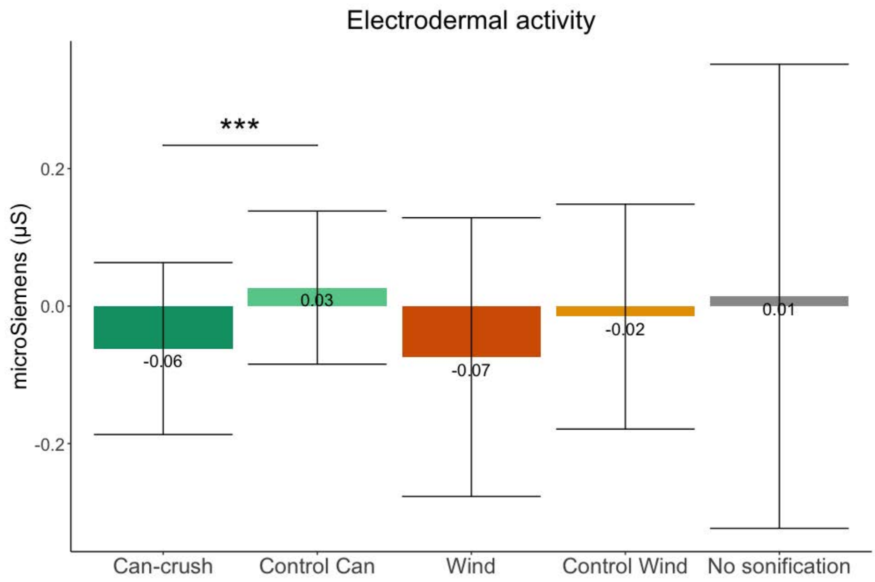


FIGURE 7.2: MEAN (±SE) ELECTRODERMAL ACTIVITY (EDA) BY CONDITION FOR "WALK" (*** INDICATES $P < .001$).

b) Effects of sound on bodily feelings

As shown in TABLE 7.4, when comparing the "Wind" and "Control Wind" conditions, results showed that the "Wind" sound gave participants the feeling of being more in control of their movement ($z = -2.135, p = .033, r = .296$) and of being the agent of the sounds ($z = -3.416, p < .001, r = .473$), and it also made them feel more comfortable ($z = -2.505, p = .012, r = .347$) than the "Control Wind" sound. Comparing "Wind" and "No Sonification", the "Wind" sound made participants feel their breath/heart more accelerated ($z = -2.066, p = .039, r = .286$), and less tired ($z = -1.993, p = .046, r = .276$) than with "No Sonification". Comparing "Control Wind" and "No Sonification", participants felt breath/heart more accelerated ($z = -2.138, p = .033, r = .296$) in the "Control Wind" condition. Participants felt more flexible with "Can-crush" than with "Control Can" ($z = -1.933, p = .053, r = .276$). Moreover, they felt more flexible ($z = -2.521, p = .012, r = .349$) with "Control Can" than with "No Sonification".

c) Effects of sound on movement behavior

The movement data showed significant effects in heel-ground contact time ($F(4,96) = 2.89, p = .026, \eta 2 = .107$); follow-up t-tests showed that participants spent more time with their heel stepping on the ground with the "Control Can" than with the "Can-crush" ($t(24) = -3.096, p = .005, d = .619$) and than with "No Sonification" ($t(24) = 2.549, p = .018, d = .509$); see

FIGURE 7.3a. Similar effects were found for stance time ($F(4,96) = 3.29, p = .014, \eta 2 = .121$). The stance time increased when participants listened to the "Control Can" as compared to the "Can-crush" ($t(24) = 3.005, p = .006, d = .601$) and "No Sonification" ($t(24) = 2.352, p = .027, d = .470$) conditions, see TABLE 7.3b. It is worth mentioning that the longer the participant is with the feet on the ground the less PA is performing, due to slow steps. However, this behavior did not relate to the reported feelings of tiredness and heaviness, where participants with all the conditions reported feel less tired, and with no changes in weight [33]. Finally, there were non-significant effect in the downwards foot acceleration ($F(4,96) = 2.1, p = .087, \eta 2 = .080$); see FIGURE 7.4. However, follow-up t-tests showed less downwards acceleration in the "Can-crush" than in "No Sonification" condition ($t(25) = -2.319, p = .029, d = .454$).

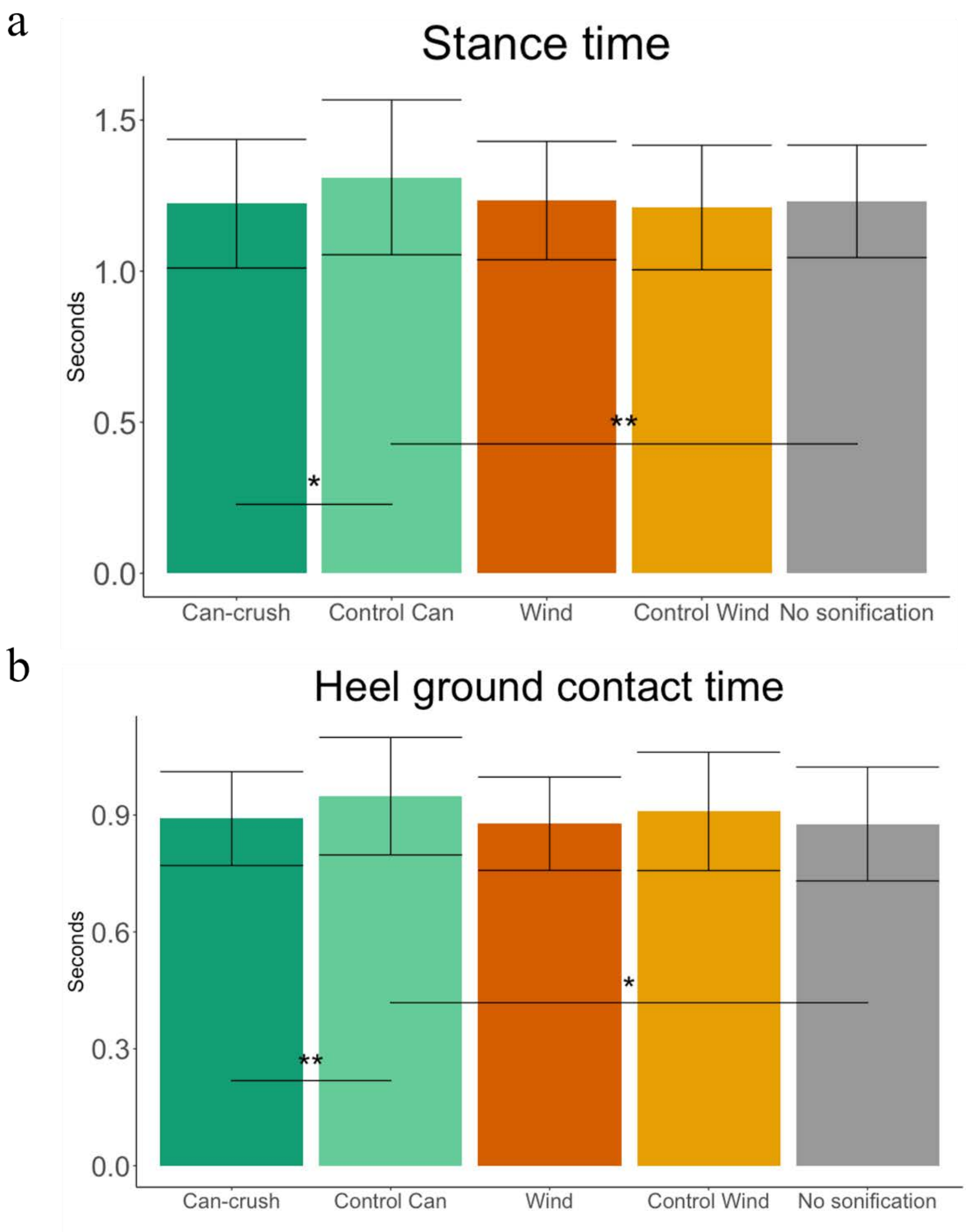


FIGURE 7.3: MEAN (±SE) A) STANCE TIME AND B) HEEL-GROUND CONTACT TIME BY CONDITION FOR "WALK". THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

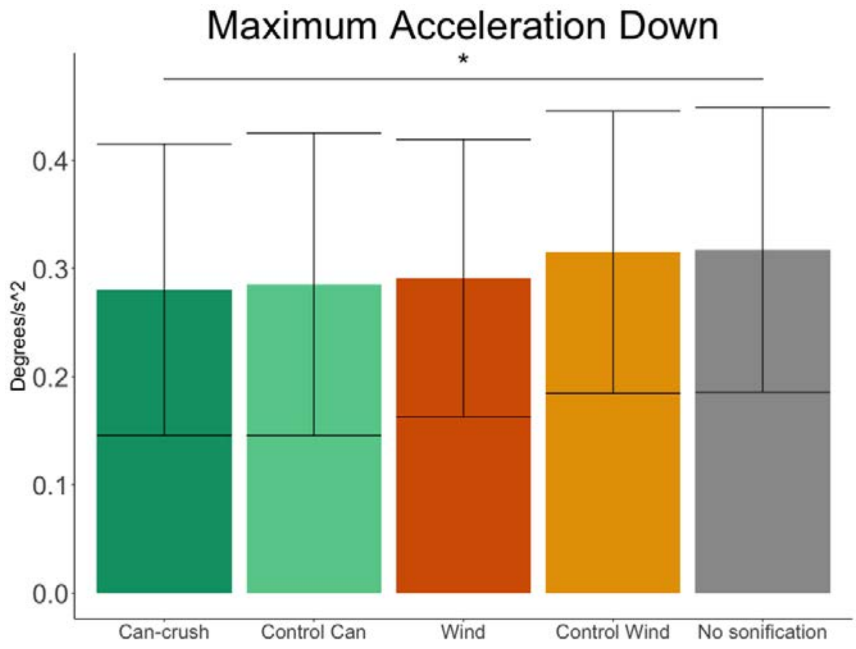


FIGURE 7.4: MEAN (±SE) ACCELERATION DOWN BY CONDITION FOR "WALK". THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05).

7.1.3.2. Effects of sound condition during "Thigh stretch"

TABLE 7.5: MEDIAN (RANGE) FOR EMOTION AND BODY FEELINGS QUESTIONNAIRE ITEMS SHOWING SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS FOR THE THIGH STRETCH EXERCISE. QUESTIONNAIRE ITEMS WERE 7-POINT LIKERT-TYPE ITEMS, EXCEPT FOR VALENCE AND AROUSAL WHICH WERE 9-POINT LIKERT-TYPE ITEMS.

Scales	**Sound conditions during Thigh Stretch**				
	Mechanical	**Water**	**Wind**	**Tone**	**No Sonification**
Valence/Happiness	6 (4 – 9)	7 (4 – 9)	6 (1 – 9)	5.5 (3 – 9)	5 (3 – 9)
Arousal/Excitation	5 (1 – 8)	4 (1 – 7)	5 (1 – 8)	5 (1 – 7)	4.5 (1 – 7)
Flexibility	4 (2 – 7)	5 (2 – 7)	4.5 (2 – 7)	4 (1 – 7)	4 (1 – 7)
Tiredness	3 (1 – 6)	3 (1 – 6)	3 (1 – 6)	3 (1 – 7)	4 (1 – 6)
Heart/Breath Accelerated	4 (1 – 6)	4 (1 – 5)	4 (1 – 6)	4 (1 – 6)	4 (1 – 6)
Fluidity	5 (2 – 7)	5 (2 – 7)	5 (1 – 7)	5 (2 – 7)	4.5 (1 – 7)
Movement control	6 (3 – 7)	6 (3 – 7)	5.5 (2 – 7)	6 (3 – 7)	5.5 (2 – 7)
Proprioception	6 (4 – 7)	6 (3 – 7)	6 (3 – 7)	6 (3 – 7)	6 (2 – 7)
Building muscles	5 (1 – 7)	3 (1 – 7)	3 (1 – 7)	4 (1 – 7)	4 (1 – 7)
Agency	6 (1 – 7)	6 (1 – 7)	6 (1 – 7)	5 (1 – 7)	–
Comfort	4.5 (3 – 7)	6 (2 – 7)	4 (1 – 7)	4 (2 – 7)	–

a) Effects of sound on emotional state

The first two items in TABLE 7.5, show the results on self-reported happiness and excitation. These self-reports were complemented with physiological EDA and BVP data. There were no significant differences in arousal between conditions, with results showing that participants felt close to a neutral state. In the case of happiness, participants reported that they felt happier with the sound conditions of "Water" and "Wind". In particular, participants felt happier with "Water" ($z = -2.56, p = .010, r = .355$) and "Wind" ($z = -2.43, p = .015, r = .336$) than with the "Tone" condition. They also felt happier with the "Wind" versus the "No Sonification" condition ($z = -2.01, p = .044, r = .278$). The analyses of the physiological data revealed that there were not significant effects in EDA ($X^2(4) = 0.410, p = .982$) or BVP ($X^2(4) = 3.818, p = .431$) ", FIGURE 7.5.

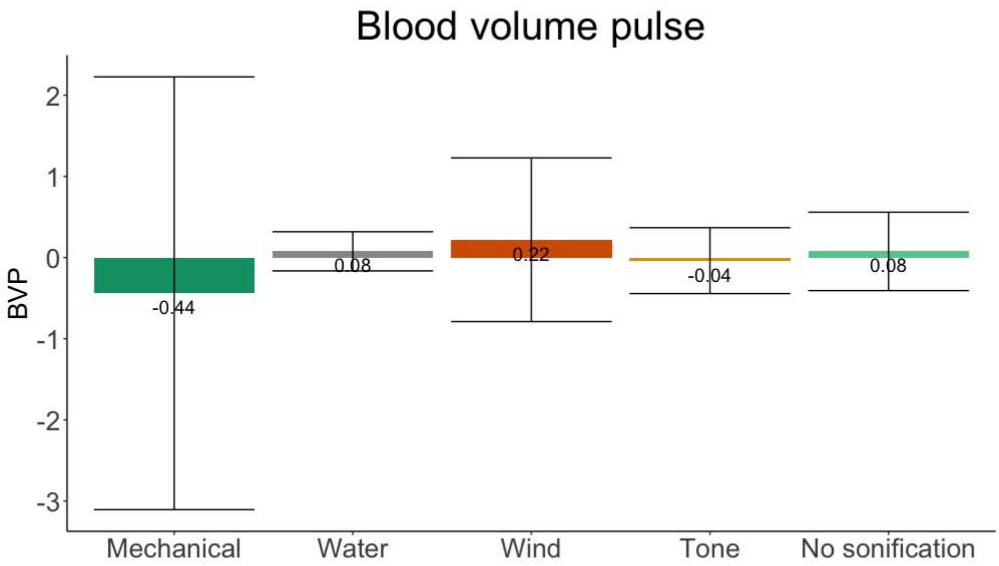


FIGURE 7.5: MEAN (±SE) BLOOD VOLUME PULSE (BVP) BY CONDITION FOR "THIGH STRETCH".

b) Effects of sound on body feelings

As shown in TABLE 7.5, in the "Mechanical" vs the "Tone" condition, participants had a higher sense of proprioception ($z = -1.91, p = .056, r = .264$) and of agency over the sound ($z = -2.0, p = .045, r = .277$), but felt less comfortable ($z = -2.3, p = .021, r = .318$). Comparing "Mechanical" with "Water", participants felt to a larger extent that the sound was produced by their movement with the former ($z = -3.31, p = .001, r = .459$). Moreover, the "Mechanical" sound made participants feel heavier ($z = -2.06, p = .040, r = .285$) but with their muscle working harder ($z = -2.22, p = .027, r = .302$) than the "No Sonification" condition. With the "Tone" vs. "No Sonification", they felt lighter ($z = -1.95, p = .051$), quicker ($z = -2.099, p = .036, r =$

.291), and more fluid ($z = -2.38, p = .081$). With "Water" vs. "Tone", participants felt less tired ($z = -2.18, p = .029, r = .302$), more flexible ($z = -2.36, p = .018, r = .327$), lighter ($z = -3.08, p = .002, r = .427$), more comfortable ($z = -3.59, p < .001, r = .497$), and more motivated ($z = -2.04, p = .041, r = .282$). With "Water" vs. "No Sonification", participants felt less tired ($z = -2.64, p = .008, r = .366$), lighter ($z = -3.67, p < .001, r = .508$), quicker ($z = -2.69, p = .007, r = .373$), more agile ($z = -2.35, p = .019, r = .325$), more fluid ($z = -2.34, p = .019, r = .324$), and they found the exercise easier ($z = -2.29, p = .022, r = .327$). With "Wind" vs. "Tone", participants felt more motivated ($z = -3.35, p = .001, r = .464$), more agile ($z = -2.11, p = .035, r = .292$), more comfortable ($z = -3.35, p = .001, r = .464$), and less tired ($z = -2.04, p = .041, r = .282$). Comparing "Wind" vs. "No Sonification", participants felt more fluid ($z = -2.04, p = .042, r = .282$), lighter ($z = -3.80, p = .000, r = .526$), more agile ($z = -3.19, p = .001, r = .442$) and less tired ($z = -2.79\ p = .005, r = .386$).

c) Effects of sound on movement behavior

Unless the analysis of the movement data showed there was a difference between conditions (*) in time down, it was non-significant effect ($F(4,88) = 2.41, p = 0.056, \eta 2 = 0.099$). Follow-up T-tests comparing all sound conditions revealed slower downwards movement in the "Mechanical" versus "Tone" condition($t(23) = 2.61$; $p = .016$). Sound had an effect on the downwards acceleration ($F(4,88) = 4.1, p = .004, \eta 2 = .157$), concretely: follow-up T-tests showed higher acceleration in the "Water" condition vs. all other conditions: "Mechanical" ($t(22) = 3.83$; $p < .001, d = .798$), "Tone" ($t(24) = 3.92$; $p < .001, d = .784$), "Wind" ($t(24) = 2.93$; $p = .007, d = .586$) and "No Sonification" ($t(24) = 2.04$; $p = .053$), see FIGURE 7.6a. "Water" resulted in a smaller deceleration in the upwards movement than the other conditions ($F(4,88) = 3.82, p = .007, \eta 2 = 0.148$) ("Water" versus "Mechanical ($t(22) = 3.91, p < .001, d = 0.814$), versus "Tone" ($t(24) = 4.1, p < .001, d = 0.820$), versus "Wind" ($t(24) = 3.15, p = .004, d = .630$), versus "No Sonification" ($t(24) = 3.11, p = .005, d = .605$)), see FIGURE 7.6b.

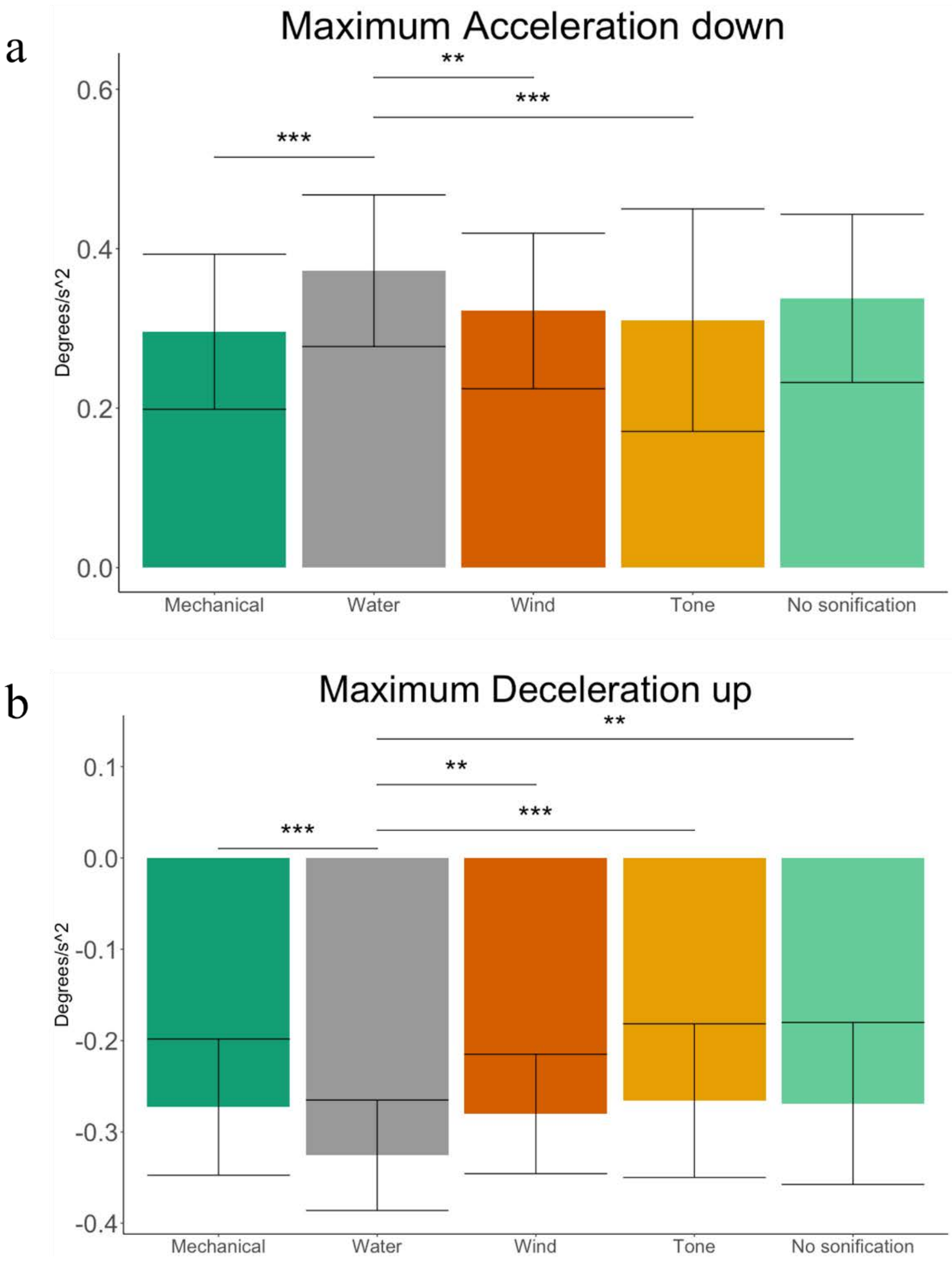


FIGURE 7.6: MEAN (±SE) DOWNWARDS ACCELERATION AND UPWARDS DECELERATION BY CONDITION IN "THIGH STRETCH". THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

7.1.4. Conclusion

This study aimed to investigate the use of movement sonification to change BP, emotional state, and movement behavior with the ultimate goal of enhancing PA. "Walk" and "thigh stretch" exercises were focused on home-based, and they were investigated the effects of different movement sonifications. The effects of sound condition on the three dimensions aforesaid were observed.

7.1.4.1. "Walk" exercise

Results showed that with the "Wind" sound, participants felt more in control of their movements and more comfortable than in its control sound condition, and that they reported feeling less tired than in the "No Sonification" condition. This was despite the fact that with "Wind" they felt their heart/breath more accelerated, and they felt less happy and more excited, than with "No Sonification". There were no significant differences in gait between the "Wind" and its control or "No Sonification" condition, which suggests that while this sound led to changes in body feelings, it did not disrupt participants' natural walking. Our findings link to works using a related "Wind" sound during spontaneous movements for autism therapy, which reported that this sound was rated as evoking more expressive, fluid, and energetic movements [126].

Further, participants felt more flexible with the "Can-crush" sound than with its control sound condition. Regarding gait, participants spent less time in contact with the ground in the "Can-crush" condition than in the "Control Can" condition, which means less PA in the "Control Can" condition and may relate to feelings of heaviness and tiredness in this condition: this relation between bodily feelings and gait was indeed observed in studies that manipulated "walk" sounds to make them consistent with those produced by a heavier body [17], [33]. Results in EDA and in self-report showed a higher arousal in the "Control Can" condition: it seems participants felt some sort of stress when performing the exercise with this sound. While the "Control Can" condition seems to induce excitation on participants, more research is needed to understand whether excitation comes together with a positive or a negative emotional state (e.g., stress or positive excitement) [155]–[157].

More related to the study aim is the observed (non-significant) effect in less foot downwards acceleration in the "Can-crush" condition vs "No Sonification". Going back to gait biomechanics, downwards acceleration reflects in a reduction in the vertical load, this is lower applied force to hold one's own weight [158]. In this light, less down acceleration in "Can-crush" may link to higher force or PA.

7.1.4.2. “Thigh stretch” exercise

Results indicate relevant effects, in relation to the study aims, for the “Mechanical”, “Water” and “Wind” conditions. On the one hand, with the “Mechanical” sound participants felt heavier and more tired than with “Water” and “Wind” sounds, which may relate to the fact that they also felt their muscles were working harder in the “Mechanical” condition. Nevertheless, for this condition participants had a better sense of proprioception as compared to the “Tone” condition. Regarding movement data, the downwards movement was slower for the “Mechanical” than for the control “Tone” and it was less accelerated than in the “Water” condition. This may link to the questionnaire results related to proprioception, agency, or sense of building muscles – participants may slow down their movement as a result of being more aware of it or to increase the feeling of one’s muscles being working harder. Previous works have found that simple sonifications that are informative of movement (such as “Mechanical” sound informing of angle changes) are more effective for increasing awareness and performance of movement during physical rehabilitation [41]. Other works have found that tone sounds increase awareness and performance e.g., in sports activities [23], [128], but note that, differently from the “Tone”, they were informative as movement modulated the frequency of the tone. The fact that only effects were observed in performance in the downwards movement may relate to one needing some exposure to sound for the effect to build.

On the other hand, with “Water” participants felt more flexible than with “Tone”, and they also felt lighter and quicker than with “Tone” and “No Sonification”. With “Water”, as well as with “Wind”, they felt less tired, more comfortable, more motivated, and happier than with “Tone”; and they felt more agile, less tired, found the exercise easier to perform and their movements more fluid than in the “No Sonification” condition. With “Wind” participants felt happier than with “No Sonification”. Meanwhile, for the results of “Water” sound were found an increase in upwards deceleration and in downwards acceleration as compared to all the other conditions. These changes in behavior may link to the observed feelings of being lighter and quicker than with the control “Tone”, and of feeling more agile, finding the exercise easier and feeling their movements were more fluid than in the “No Sonification” condition. Previous works using a similar “Water” sound for sonifying trunk bend angle during stretching movements for physical rehabilitation have found out that this sound is effective for relaxation and motivation [41]. Other works have highlighted that marking the start and end of movement (such as our “Water” sound does) results in more rewarding experiences, and builds on self-efficacy [25], [39].

7.2. Study 2: to evaluate the effect of sound on “leg lift” exercise

We[9] run a deployment study focused on the “leg lift” exercises. The exercise is related to the effect of sound on feelings of body strength. The aim is to analyze whether sonification could ultimately improve a person’s actual and perceived body lifting during exertion.

7.2.1. Author contributions and related publication

In this study, I contributed to the conception and design of the work; the development of the sonification mappings and the software and hardware for such movement sonification. I assisted with the software/hardware during the acquisition of the data, and I was responsible for the analysis of all the data, its interpretation and writing of it with supervision from other senior researchers from the research team.

7.2.2. Methods

7.2.2.1. Participants and setting

The exercise with twenty-four participants (M_{age}= 26.95, SD_{age}= 6.40, Range= 18 – 50; n=24, 16 females, 8 male). Participants were selected from the University College London (UCL) student pool. The study was approved by the UCL Interaction Centre ethics committee (Appendix G). As compensation for their participation, participants were asked to choose between getting 1 academic credit for their time or entering a raffle to win a £50 Amazon voucher.

The experiment took place in a lab. Before the “leg lift” exercise, participants were taken to the lab and given an information sheet explaining the procedure and how the participant’s data would be used; lastly, they signed a consent form confirming that their data can be used. Afterwards, participants were asked to fill in the IPAQ and IFiS questionnaires to give an idea of their fitness level and perception of their PA level. After forms were filled out, the participants put on the SoniShoes and sat on a chair.

The IFiS showed that the participants in this “leg lift” study perceived their fitness level to be good on all the IFiS items: on a scale from 1 (very poor) to 5 (very good), their scores showed a median = 4 (with a range of 2 – 5) for general physical fitness, 4 (1 – 5) for cardiorespiratory condition, 4 (1 – 5) for muscular strength, and 4 (2 – 5) for speed level, being 4 considered in the “good” level. The

[9] As my Ph.D. thesis was developed in the framework of a bigger research project www.magicshoes.esthe study was in collaboration with a PhD Student from Universidad Loyola Andalucía, Patricia Rick, and with researchers at University College London, where the data was collected.

flexibility level was in the "average" level 3.5 (1 – 4). The IPAQ results measuring the PA level showed that 1 participant fell into the low PA level (< 600 MET/week), 9 participants showed a moderate PA level (from 1500 – 3000), and 14 participants showed a high PA level (>3000).

Exercises

For the "leg lift" task, the seated participants were asked to raise his/her leg once to allow the shoes to be calibrated. The minimum (foot on the floor) and maximum (leg raised fully) positions were recorded and used to set the start and end points of the sonification stimuli, see TABLE 7.6. In each sound condition, participants raised their left foot until it was as close to horizontal as the participants could manage, then returned the foot to the floor with the left leg not touching the chair. This constitutes one repetition and participants performed five repetitions of the exercise.

TABLE 7.6: DESCRIPTION OF THE "LEG LIFT" EXERCISE.

Exercises	Description	Example	
		Trajectory -----	
		Start position •	**Objective** ➤
Leg lift	**Initial Position**: Sit with your back against the back of the chair.		
	Trajectory: Straighten one leg then lift it.		
	Objective (strength): Leg lifted until the thigh comes off the chair. **After the objective**: Lower the foot to the ground to return to the initial position.		

7.2.2.2. Apparatus and stimuli

a) SoniShoes: desktop version

The same prototype used in Study 1, SoniShoes was used. For more details see Chapter 5, Section 5.2.2.

b) "Leg lift": sound stimuli

There were four sound conditions and a "No Sonification" condition (see TABLE 7.7). Two of the stimuli were metaphorical sonifications that represented naturalistic-environmental sounds, "Water" and "Wind" (also used in the "Thigh stretch" experiment). One other stimulus was an abstract or nonnaturalistic sound, "Up". Lastly, there was a control sound, "Continuous". The "Water" sound aimed to replicate the senses of continuous water sounding during the trajectory with a "splash" sound presented when reaching the end of the upwards movement (as if the leg was emerging from the water) and when starting the downwards movement (as if the leg was getting into the water). The "Wind" sound was reproduced using pink noise and changes in frequency (from 220 Hz to 3520 Hz) according to the angle changes of the leg. The "Up" sound was created from musical notes, changing from C5 to C6 designed based on previous studies on changing pitch sounds [16] and refers to the associations with vertical movement [159]. The "Up" sound was designed to replicate the effect of a "boing" sound or a sound that "pulls the body" when the leg starts to move [68]. The "Continuous" sound played during the trajectory of the movement and kept a constant frequency of 440 Hz. A fifth, "No Sonification" condition, was added to the experimental design.

The "No Sonification" and "Continuous" conditions were used as control conditions, to understand whether sound stimuli with metaphors associated (i.e., Water, Wind) or that change in pitch make an effect independently of not receiving sound stimuli or just listening to a sound during the exercise [16].

7.2.2.3. Measures

For data collection were used a self-report of feelings, consisting of two BP questionnaires; both contained 7-point Likert-scale response items, except for one of the items related to perceived reached angle. Questionnaire 1 was responded by participants per condition and questionnaire 2 was filled out by participants after all 5 conditions were completed.

Questionnaire 1 was based on the one used in Study 1, with some slight differences in the items due to the aim of the study, to see the effect of sound on feelings of body strength or behavior on applied strength (Appendix H and Appendix I). The items were related to how participants felt about their bodies, their body movement, the sound, and their performance in the task. The items asked about the following:

- feelings of difficulty in raising the leg to the final position, and ranged from "very difficult" (1) to "very easy" (7), **Difficulty**
- feelings of strength while doing the exercise, and ranged from "weak" (1) to "strong" (7), **Strength**
- feelings of speed while doing the exercise, and ranged from "slow" (1) to "quick" (7), **Speed**

- feelings of agility while doing the exercise, and ranged from “not agile” to “agile”, **Agility**
- feelings of one’s muscle being working while doing the exercise, and ranged from “not working at all” (1) to “working hard” (7), **Building muscles**
- feelings of being capable of completing the exercise, arising while doing it, and ranged from “incapable” (1) to “capable” (7), **Capability**
- feelings of being able to tell where one’s fool exactly was while doing the exercise, and ranged from “could not tell” (1) to “could tell” (7), **Proprioception**
- feelings of leg weight while doing the exercise, and ranged from “light” (1) to “heavy” (7), **Weight**
- feelings of movement fluidity while doing the exercise, and ranged from “not fluid” (1) to “fluid” (7), **Fluidity**
- feelings of exercise effort, and ranged from “effortless” to “challenging”, **Challenge**
- feelings about the sound being produced by oneself, and ranged from “not produced by me” (1) to “produced by me” (7), **Agency**
- feelings of comfort about the sound heard, and ranged from “uncomfortable” (1) to “comfortable” (7), **Comfort**
- feelings of motivation caused by the sound heard, and ranged from “did not motivate me to do the exercise” (1) to “motivated me to do the exercise” (7), **Motivation**
- feelings of naturality doing the exercise, and ranged from “strange, artificial” (1) to “natural” (7), **Naturality**
- the perceived reached angle reported in FIGURE 7.7, and ranged from 0 to 90 degrees, **Peak Angle**

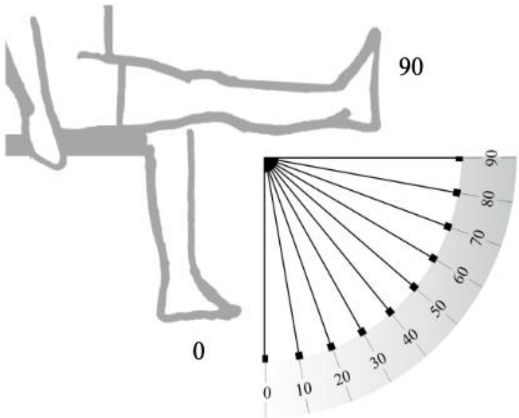


FIGURE 7.7: THIS GRAPH ALLOWED PARTICIPANTS TO REFLECT ON THE PERCEIVED REACHED ANGLE AFTER PERFORMING THE “LEG LIFT” EXERCISE.

The questionnaire 2 was filled out by participants after all 5 conditions had been completed, so that participants could compare their feelings across the different conditions. Only five of the items in questionnaire 1 were kept in questionnaire 2: difficulty, building muscles, capability, challenge, and motivation (Appendix J).

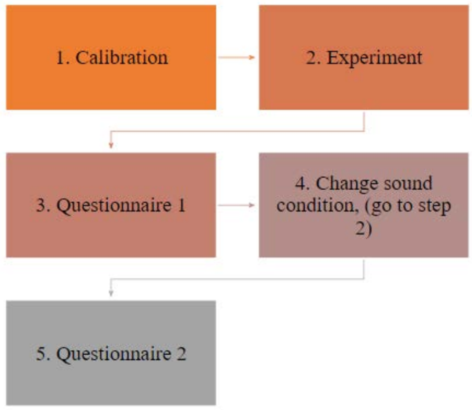
Lastly, in terms of the **behavioral changes** in the “leg lift” exercise, sensor data were used, and the parameters extracted were the same as those extracted in study 1 for the “thigh stretch” exercise: mean and peak angle, velocity, acceleration, and time during the exercise, including both upwards and downwards parts of the movement, see Section 7.1.2.3, *b) behavioral data*.

7.2.2.4. Experimental procedure

As in study 1, the study followed a within-subjects design, focused on the “leg-lift” task, with five sound conditions. Participants were seated and performed the leg lift movement with “Water”, “Wind”, and “Up” as experimental conditions and “No Sonification” and “Continuous” as control conditions, see details in TABLE 7.7. The experimental procedure was as follows (see TABLE 7.7 for a graphical description of the procedure). First, calibration was performed before the start of the task: participants helped to store the information of the leg in two positions. For the start position (or minimum position), the participants bend the knee to form 90 degrees. For the end position (or maximum position), the leg is extended completely to form an angle of 0 degrees. Second, participants were asked to perform the exercise (i.e., leg raise, five times, see TABLE 7.6) with one of the sound conditions. Third, participants completed Questionnaire 1 referring to how they felt and how they perceived their body movements during the task (see Measures Section 7.1.2.3 and Appendix

Appendix H and Appendix I). Participants repeated steps 1 and 2 with each sound condition. The order of the sound conditions was randomized to balance for practice bias to avoid the anchor effects of the initial value. Finally, once all conditions were completed, a final Questionnaire 2 was given to the participants to ask them to compare each stimulus (see Appendix J). The whole study lasted approximately 30 minutes.

TABLE 7.7: DESCRIPTION OF THE SOUND CONDITIONS USED AND THE NUMBER OF REPETITIONS IN EACH EXERCISE, “LEG-LIFT”.

Movement	**Condition**	**Time/ repetitions**	**Procedure**
Leg lift (Strengthening & Toning goal program)	No Sonification	5 repetitions (Hold 1 second and release)	
	Water		
	Wind		
	Up		
	Continuous		

7.2.2.5. Data Analysis

The questionnaire data was analyzed using Friedman tests to compare all the experimental conditions among them, as non-parametric tests are recommended for Likert scale data not normally distributed [146]. Wilcoxon signed-rank tests were further used as post-hoc tests (by using SPSS Statistics 26.0). The significance level for all statistical tests was fixed as $p < .05$, and complemented with the corresponding effect size statistic: $r = Z/\sqrt{N}$ [147] (large effect is .5, a medium effect is .3, and a small effect is .1). Separate tests were conducted to analyze the data from the different items of the questionnaire: perceptions of strength, capability, building muscles, difficulty of the exercise, challenge to perform the activity, and the reached peak angle.

The movement data were evaluated with repeated measures analyses of variance (ANOVA). Separate analyses were conducted for each of the movement parameters extracted from the accelerometer and gyroscope affixed to the participant’s ankle: mean and peak angle, velocity, acceleration, and time during the exercise.

7.2.3. Results

7.2.3.1. Effects of sound condition on bodily feelings

TABLE 7.8 shows a summary of the results obtained from the questionnaires employed. As mentioned before (7.1.2.4), there was a questionnaire answered immediately after each of the sound conditions (Questionnaire 1), and another questionnaire answered after all the conditions were completed (Questionnaire 2).

TABLE 7.8: MEDIAN (RANGE) FOR ITEMS OF QUESTIONNAIRE 1 (DURING TASK*) AND QUESTIONNAIRE 2 (POST-TASK^) IN THE LEG LIFT EXERCISE. NOTE THAT THE POST-TASK QUESTIONNAIRE CONTAINED ONLY 5 ITEMS. ALL ITEMS WERE 7-POINT LIKERT-RESPONSE ITEMS, EXCEPT FOR THE PEAK ANGLE WHICH RANGED FROM 0 TO 90 DEGREES. NS = NO SONIFICATION.

Scales / Sound condition	**During the task**					**Post-Task**				
	Water	**Wind**	**Up**	**Continuous**	**No Sonification**	**Water**	**Wind**	**Up**	**Continuous**	**No Sonification**
Difficulty*	6 (5 – 7)	5.5 (3 – 7)	6 (4 – 7)	6 (3 – 7)	5 (2 – 7)	–	–	–	–	–
Strength*^	5 (3 – 7)	5 (4 – 7)	5 (3 – 7)	4 (1 – 6)	4 (1 – 6)	5.5 (3 – 7)	5 (3 – 7)	5 (2 – 7)	4 (1 – 6)	4 (1 – 6)
Agility*	5 (3 – 7)	5 (3 – 7)	5 (3 – 7)	5 (1 – 7)	4 (1 – 7)	–	–	–	–	–
Building ^ muscles	5 (2 – 6)	4 (2 – 7)	4.5 (1 – 6)	4 (2 – 6)	4.5 (2 – 7)	5 (1 – 7)	4 (1 – 7)	4 (1 – 7)	4 (1 – 7)	4 (1 – 7)
Capability*^	6.5 (5 – 7)	6 (4 – 7)	7 (5 – 7)	6 (3 – 7)	6 (3 – 7)	6.5 (4 – 7)	6.5 (2 – 7)	6.5 (3 – 7)	6 (2 – 7)	5.5 (3 – 7)
Proprioception*	6 (4 – 7)	6 (2 – 7)	6 (5 – 7)	6 (2 – 7)	6 (2 – 7)	–	–	–	–	–
Weight*	4 (1 – 6)	3 (1 – 6)	3 (1 – 6)	4 (2 – 7)	5 (2 – 7)	–	–	–	–	–
Fluidity*	6 (3 – 7)	6 (2 – 7)	5 (2 – 7)	5 (2 – 7)	4.5 (1 – 7)	–	–	–	–	–
Motivation*^	5 (3 – 7)	5 (1 – 7)	4.5 (2 – 7)	3 (1 – 7)	–	6 (4 – 7)	5 (2 – 7)	5 (2 – 7)	3 (1 – 6)	4 (1 – 5)
Peak Angle	90 (70 – 90)	90 (70 – 90)	88.5 (70 – 90)	85 (70 – 90)	85 (60 – 90)	–	–	–	–	–

a) Effects of sound condition on easiness of the task

The results for the item *"How easy did you find the exercise?",* which was only included in questionnaire 1, showed that there were significant differences between conditions in perception of *easiness* ($X^2(4{,}24) = 11.272\ , p =\ .024$), see FIGURE 7.8. The exercise felt easier with the "Water" sound than with the "Wind" ($Z\ = -2.085, p = .037, r =\ .300$) or "Continuous" sounds ($Z\ = -1.982, p = .048, r =\ .286$), and with the "No Sonification" condition ($Z\ = -2.803, p = .005, r =\ .300$). Moreover, the "Up" sound made the exercise feel easier than without sonification ($Z\ = -2.629, p =\ .009, r =\ .379$).

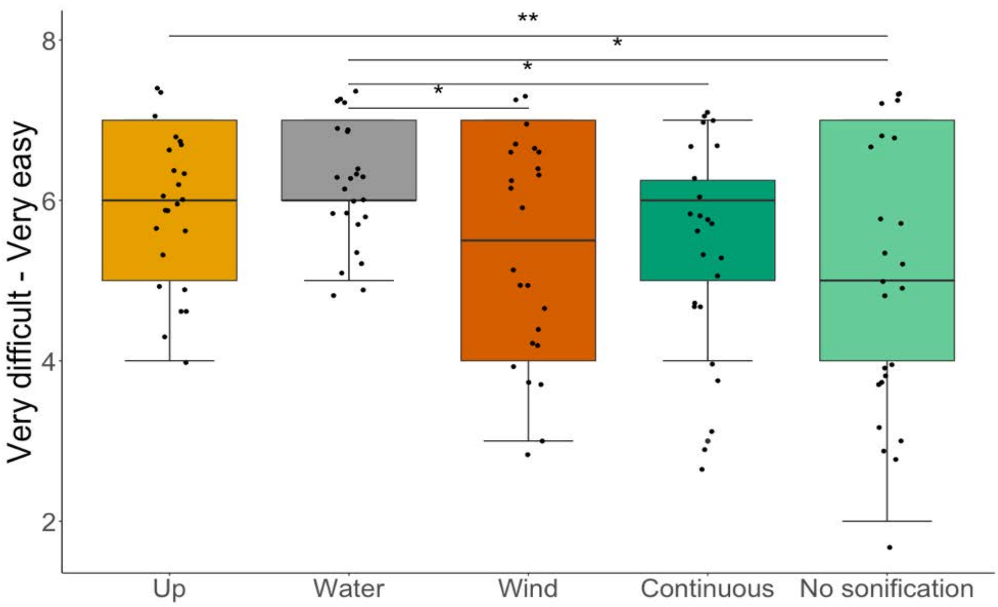


FIGURE 7.8: PERCEIVED DIFFICULTY AS SHOWN BY RESULTS IN QUESTIONNAIRE 1. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < 0.05, ** INDICATES P < 0.01, *** INDICATES P < 0.001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

b) Effects of sound condition on strength

The item, *"As I was doing the exercise I felt… (Weak to Strong)"* was included in both questionnaires 1 and 2. Friedman tests showed significant differences between conditions in the perception of **strength while doing the exercise both** in questionnaire 1 ($X^2(4{,}24) = 15.850\ , p =\ .003$) and questionnaire 2 ($X^2(4{,}24) = 29.779\ , p <\ .001$); as shown in FIGURE 7.9.

Results from questionnaire 1 showed that participants felt stronger with the "Water" ($z = -2.429, p =\ .015, r =\ .350$) and "Wind" ($z = -2.829, p = .005, r =\ .408$) sounds than with the "Continuous" sound (FIGURE 7.9a). Also, the "Wind" sound made participants feel stronger than the "Up" ($z = -2.876, p = .004, r = .415$) and "No Sonification" ($z = -2.428, p = .015, r = .358$) conditions. Lastly, the participants felt stronger with the "Up" sound than with "No Sonification" ($z = -2.270, p = .023, r = .358$).

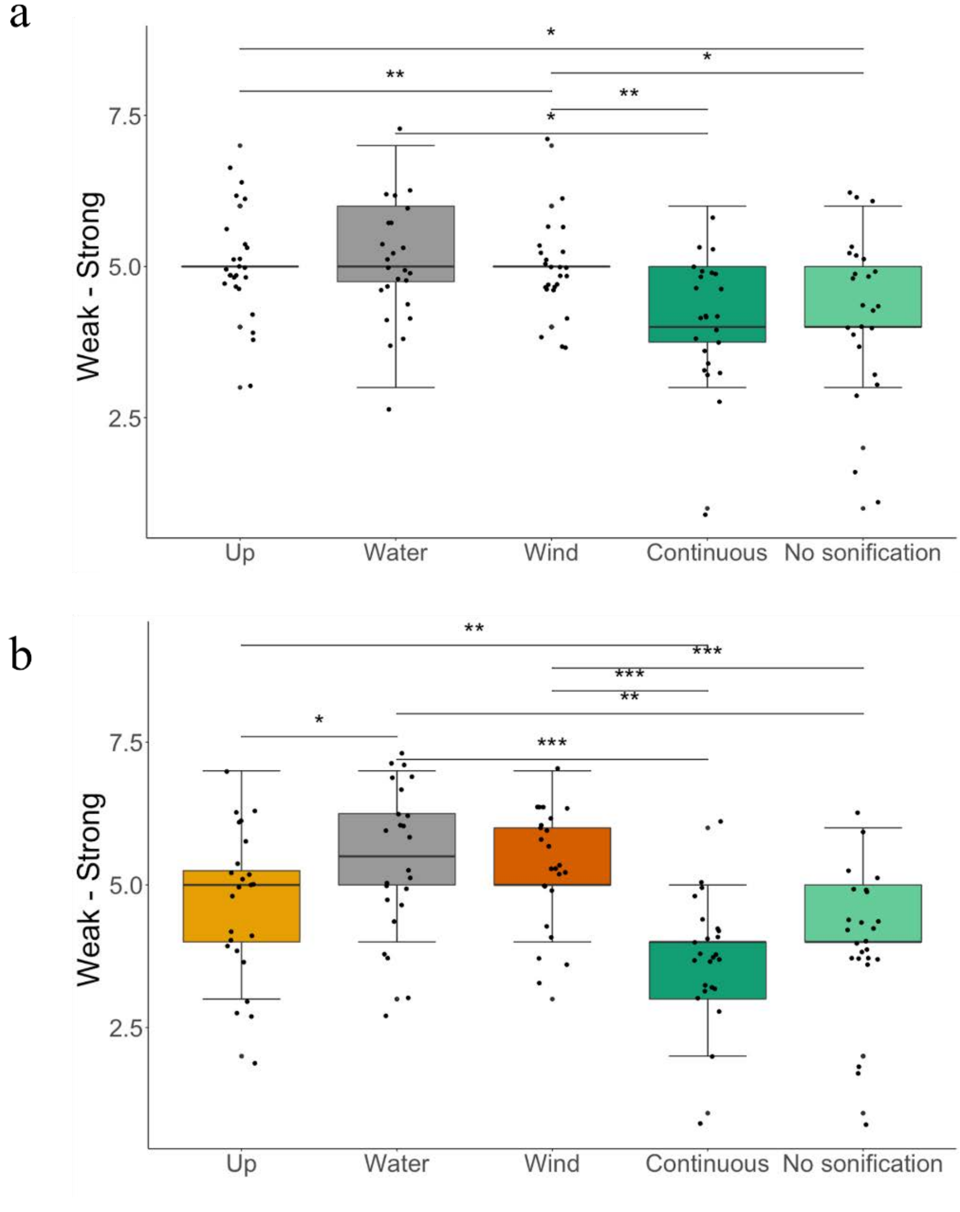


FIGURE 7.9: PERCEPTIONS OF STRENGTH AS SHOWN BY RESULTS IN (A) QUESTIONNAIRE 1 AND (B) QUESTIONNAIRE 2. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

Results from questionnaire 2 showed that participants still felt stronger with the "Water" than with the "Continuous" sound ($z = -3.440, p < .001, r = .496$), the "Up" ($z = -2.445, p = .015, r =$

.352); and "No Sonification" conditions ($z = -3.059, p = .002, r = .441$), as it can see in FIGURE 7.9b. The "Wind" sound kept the sense of being stronger than with the "Continuous" ($z = -3.704, p < .001, r = .534$) and "No Sonification" ($z = -3.324, p = .001, r = .479$) conditions. Lastly, the reflections of the participants also showed that they felt stronger with the "Up" sound than with the "Continuous" sound ($z = -2.961, p = .003, r = .427$).

c) Effects of sound condition on speed and agility

The results for the item *"As I was doing the exercise I felt (slow to quick)"* in questionnaire 1 showed there were not significant differences between the conditions ($X^2(4,24) = 7.265, p = .123$). Meanwhile, the results for the item, *"As I was doing the exercise I felt (not agile to Agile)",* in questionnaire 1 showed significant differences between the conditions ($X^2(4,24) = 12.273, p = .015$), as shown in FIGURE 7.10. The sounds of "Water" ($z = -2.131, p = .033, r = .307$), "Wind" ($z = -2.698, p = .007, r = .389$), and "Up" ($z = -2.139, p = .032\ r = .308$) increased the sense of agility with respect to the "No Sonification" condition.

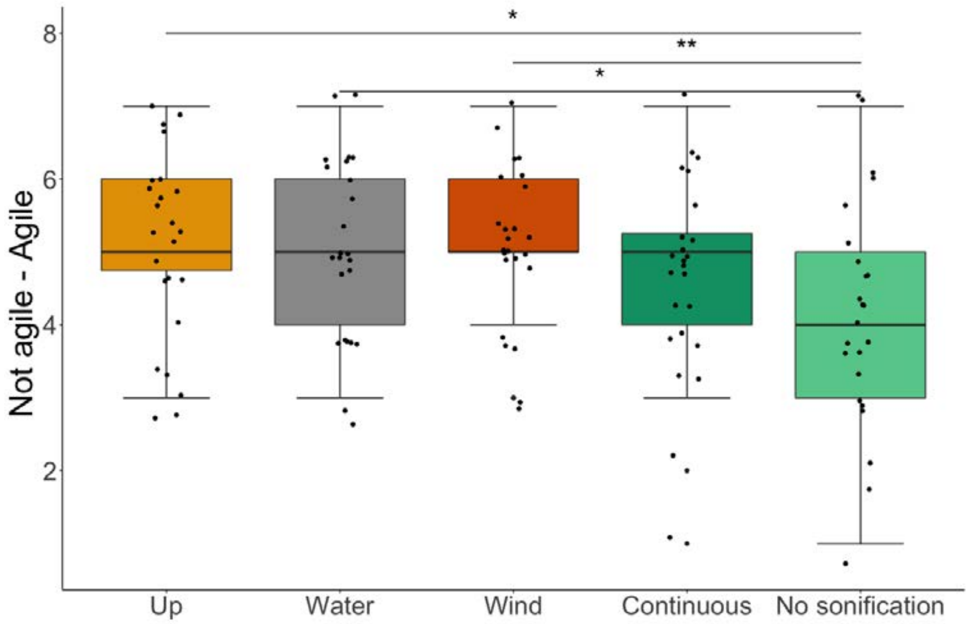


FIGURE 7.10: PERCEPTION OF AGILITY AS SHOWN BY RESULTS IN QUESTIONNAIRE 1. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

d) Effects of sound condition on building muscles

The results of the item *"As I was doing the exercise, I felt my muscle was… (Not working at all to working hard)"*, which was included in both questionnaires 1 and 2, did not show significant results for questionnaire 1 ($X^2(4,24) = 6.269\,, p = .180$) but they did show significant differences between conditions in questionnaire 2 ($X^2(4,24) = 13.165\,, p = .010$). Results from questionnaire 2 showed that participants felt their muscles worked harder with the "Water" than with the "Up" sound ($z = -3.115, p = .002, r = .449$), see FIGURE 7.11b.

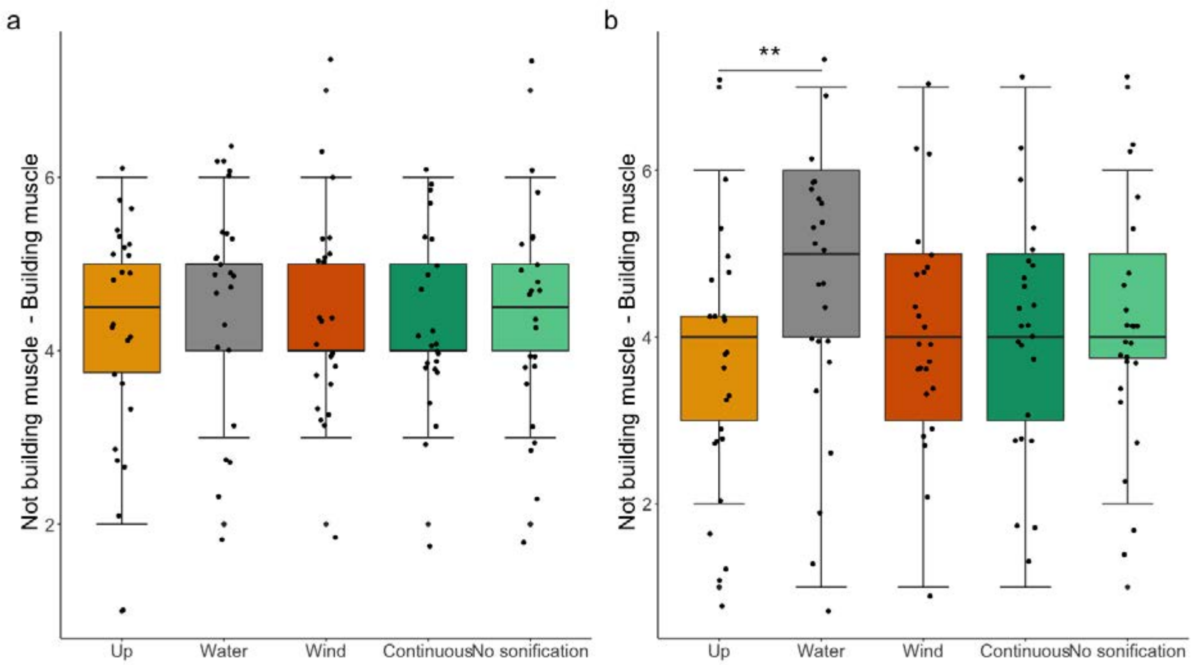


FIGURE 7.11: PERCEPTION OF "BUILDING MUSCLES" AS SHOWN BY RESULTS IN (A) QUESTIONNAIRE 1 AND (B) QUESTIONNAIRE 2. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, CORRECTED FOR MULTIPLE COMPARISONS).

e) Effects of sound condition on capability

The results of the item *"As I was doing the exercise, I felt (incapable to capable) of completing the exercise"*, which was included in both questionnaires 1 and 2, showed significant effects of condition in questionnaire 1 ($X^2(3,23) = 20.532\,, p < .001$) but not in questionnaire 2. Results from questionnaire 1, filled out immediately after each condition, showed that participants felt that the "Water" sound gave them the sense of being more capable of performing the exercise than the "Continuous" ($z = -1.996, p = .046, r = .288$) and the "No Sonification" ($z = -2.066, p = .039, r = .298$) conditions. Moreover, with the "Wind" sound the participants felt more capable of performing the exercise than with the "Continuous" ($z = -1.997, p = .046,\ r = .288$) and "No

Sonification" $(z = -2.456, p = .014, r = .354)$ conditions. However, with the "Up" sound participants felt even more capable of performing the exercise than with the "Wind" sound $(z = -2.121, p = .034, r = .306)$, as well as than with the "No Sonification" $(z = -2.658, p = .008, r = .383)$ and "Continuous" $(z = -2.859, p = .004, r = .412)$ conditions.

As it was said above, there were no significant differences between conditions in the final questionnaire 2 $(X^2(4,24) = 7.776, p = .100)$. As it can be seen in FIGURE 7.12b, the reason for this lack of significance is that participants concluded that the "Up", "Water" and "Wind" sounds evoked on them the same level of capability feelings (see also TABLE 7.8).

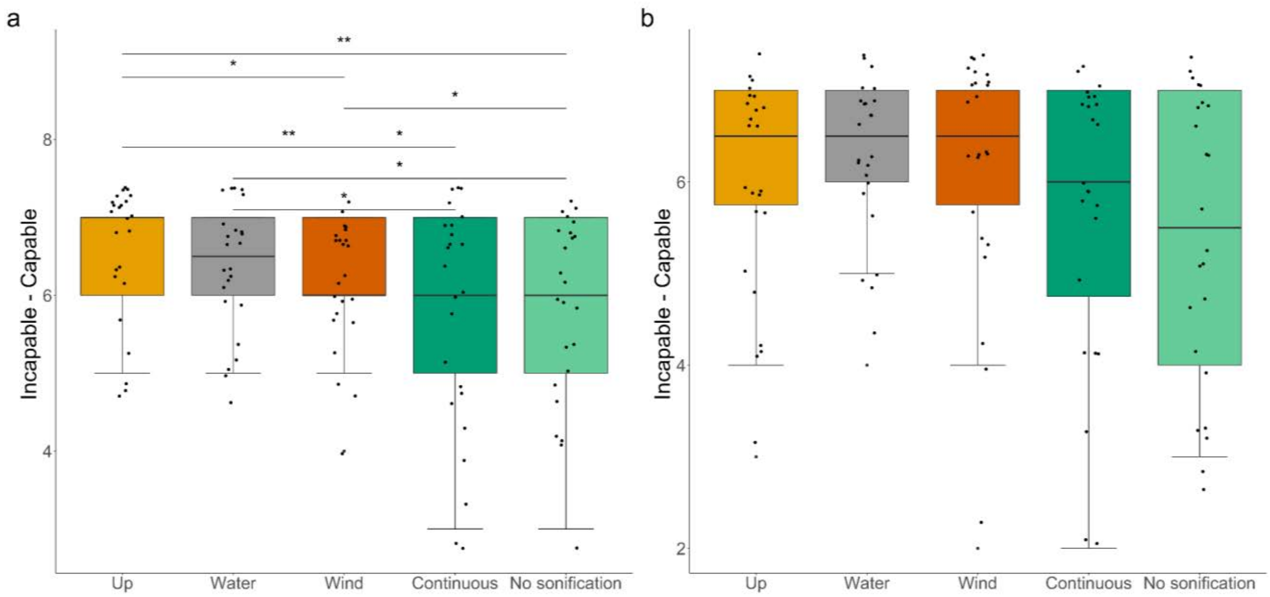


FIGURE 7.12: PERCEPTION OF CAPABILITY TO PERFORM THE EXERCISE AS SHOWN BY RESULTS IN (A) QUESTIONNAIRE 1 AND (B) QUESTIONNAIRE 2. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < 0.05, ** INDICATES P < 0.01, *** INDICATES P < 0.001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

f) Effects of sound condition on proprioception

The results of the item *"As I was doing the exercise, I felt (I could not tell / I could tell) exactly where my foot was"*, which was only included in questionnaire 1, showed significant differences between conditions $(X^2(4,23) = 10.320, p = .035)$. Participants felt they could better locate their foot during the movement (i.e., had better proprioception) with the "Up" than with the "Continuous" sound $(z = -2.490, p = .013, r = .359)$, see FIGURE 7.13.

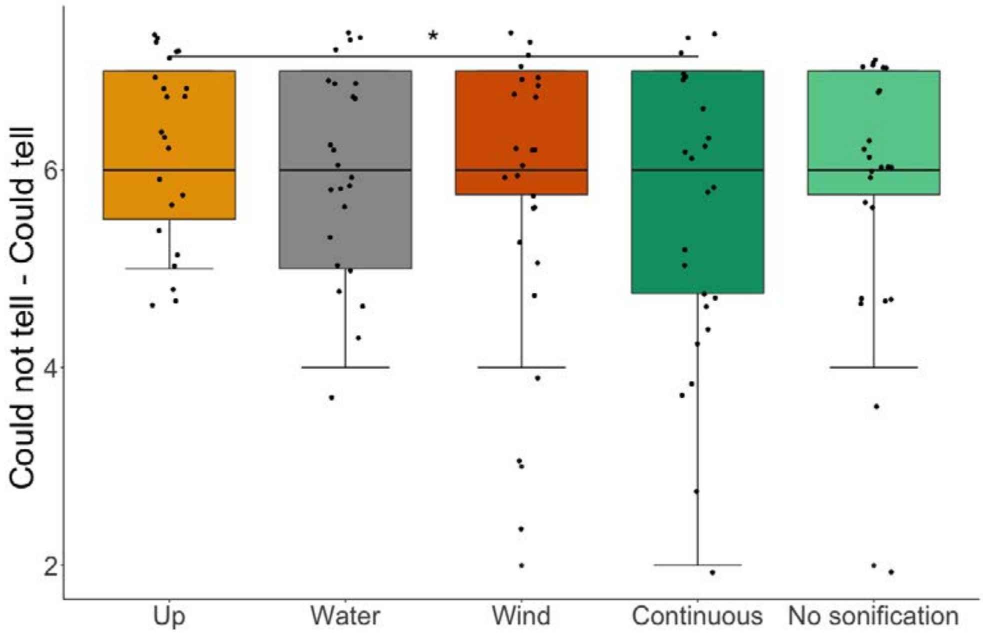


FIGURE 7.13: PERCEIVED PROPRIOCEPTION OF THE FOOT AS SHOWN BY RESULTS IN QUESTIONNAIRE 1. THE SCALE RANGES FROM "COULD NOT TELL" TO "COULD TELL" EXACTLY WHERE MY FOOT WAS. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < 0.05, ALL CORRECTED FOR MULTIPLE COMPARISONS).

g) Effects of sound condition on weight

The results of the item "*As I was doing the exercise my leg felt... (light to heavy)*" in questionnaire 1 showed significant differences between conditions ($X^2(4,24) = 18.941, p = .001$). Participants felt lighter with the "Water" sound than without sonification ($z = -1.977, p = .048, r = .285$). Also, participants felt lighter with the "Wind" than with the "Continuous" ($z = -3.096, p = .002, r = .446$) and "No Sonification" ($z = -3.457, p = .001, r = .498$) conditions. Moreover, participants perceived their leg was lighter with the "Up" sound than with the "Continuous" ($z = -2.200, p = .028, r = .317$) and "No Sonification" ($z = -3.052, p = .002, r = .440$) conditions, see FIGURE 7.14.

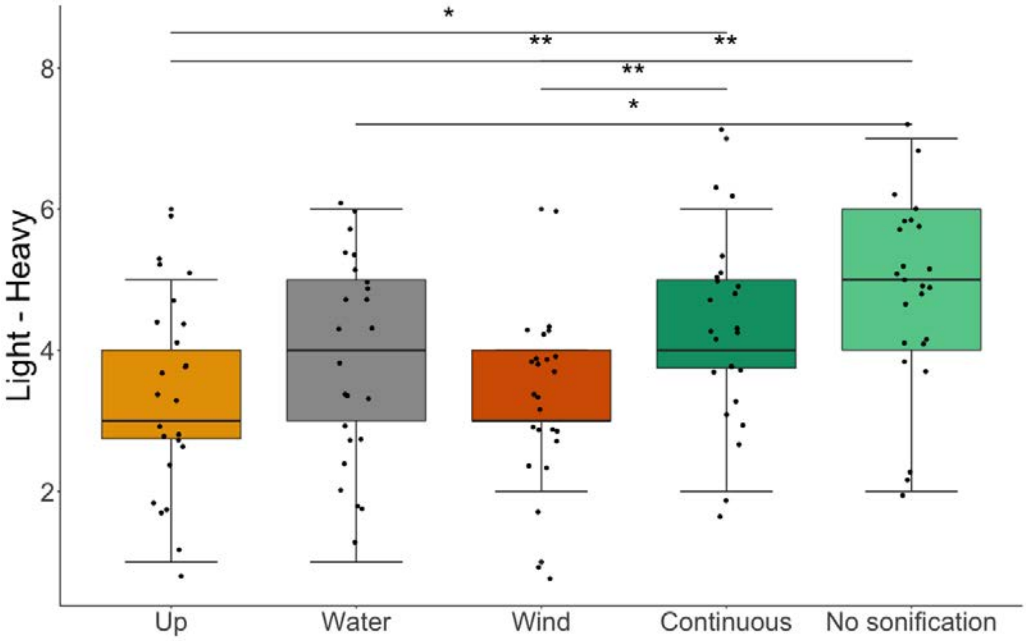


FIGURE 7.14: PERCEIVED LEG WEIGHT AS SHOWN BY RESULTS IN QUESTIONNAIRE 1. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

h) Effects of sound condition on movement fluidity

The results of the item *"As I was doing the exercise, I felt my movements were... (not fluid to fluid)"* in questionnaire 1 showed significant differences between conditions ($X^2(4{,}24) = 15.577\ , p = .004$). The "Water" sound made participants feel their movement were more fluid than with the "Up" sound ($z = -2.208, p = .027, r = .318$), "Continuous" sound($z = -2.081, p = .037, r = .300$), and "No Sonification" condition ($z = -2.483, p = .013, r = .358$). Further, the "Wind" sound helped participants to feel their movement was more fluid than without sonification ($z = -3.009, p = .003, r = .434$) , see FIGURE 7.15.

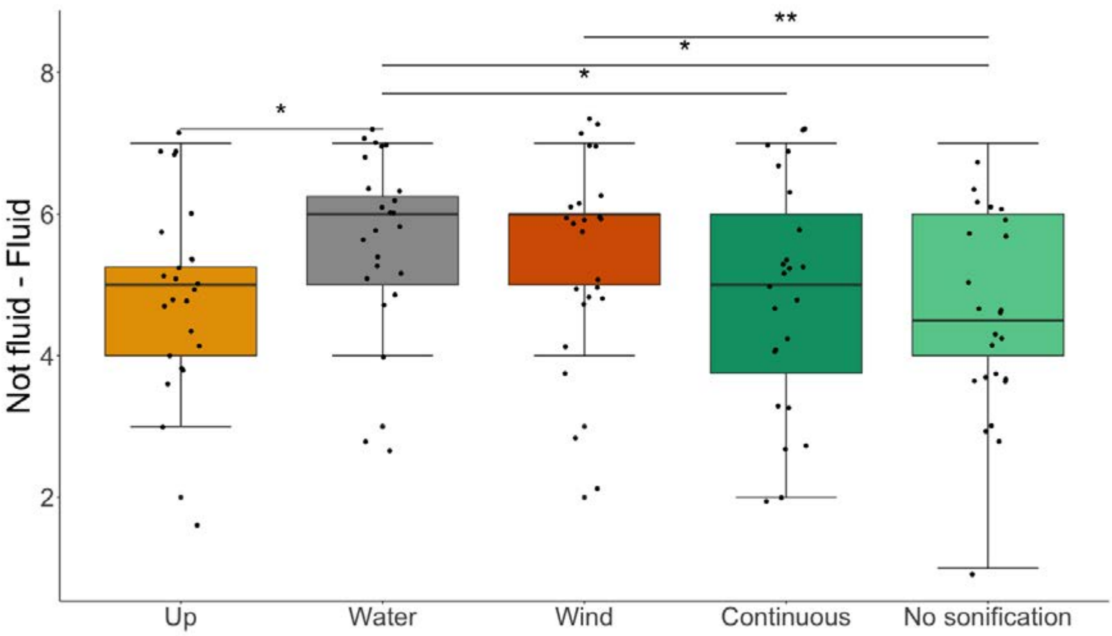


FIGURE 7.15: PERCEIVED FLUIDITY AS SHOWN BY RESULTS IN QUESTIONNAIRE 1 (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

i) Effects of sound condition on motivation

The results of the item "*The sound I heard…. (Did not motivate / motivated me) to do exercise", which was included both in questionnaire 1 and 2,* showed significant differences between conditions in both questionnaires. Results in questionnaire 1 demonstrated significant differences in the effects of the sounds accompanying the movement ($X^2(3,24) = 23.061\ , p < .001$). Participants felt more motivated to do the exercise with the "Wind" sound than with the "Continuous" sound ($z = -1.552, p = .011, r = .224$). Moreover, they also felt more motivated with the "Water" than with the "Up" ($z = -2.454, p = .014, r = .354$) and "Continuous" ($z = -3.305, p = .001, r = .477$) sounds, see FIGURE 7.16a.

In the final questionnaire 2 participants reported similar perceptions as those reported in questionnaire 1, which they had filled out during the task ($X^2(4,24) = 57.363\ , p < .001$), and they added new significant comparisons between conditions. With the "Water" condition participants felt more motivated than with the "Up" ($z = -3.542, p < .001, r = .511$), "Continuous" ($z = -4.328, p < .001, r = .624$), and "No Sonification" ($z = -4.141, p < .001, r = .624$) conditions. The "Wind" sound motivated more the participants than the "Continuous" sound ($z = -3.741, p < .001, r = 0.539$), and the "No Sonification" condition ($z = -3.790, p < .001, r = .547$). Lastly, participants perceived themselves more motivated with the "Up" sound than with the "Continuous" ($z =$

$-2.852, p = .004, r = .411$) and with the "No Sonification" ($z = -2.558, p < .011, r = .369$) conditions, see FIGURE 7.16b.

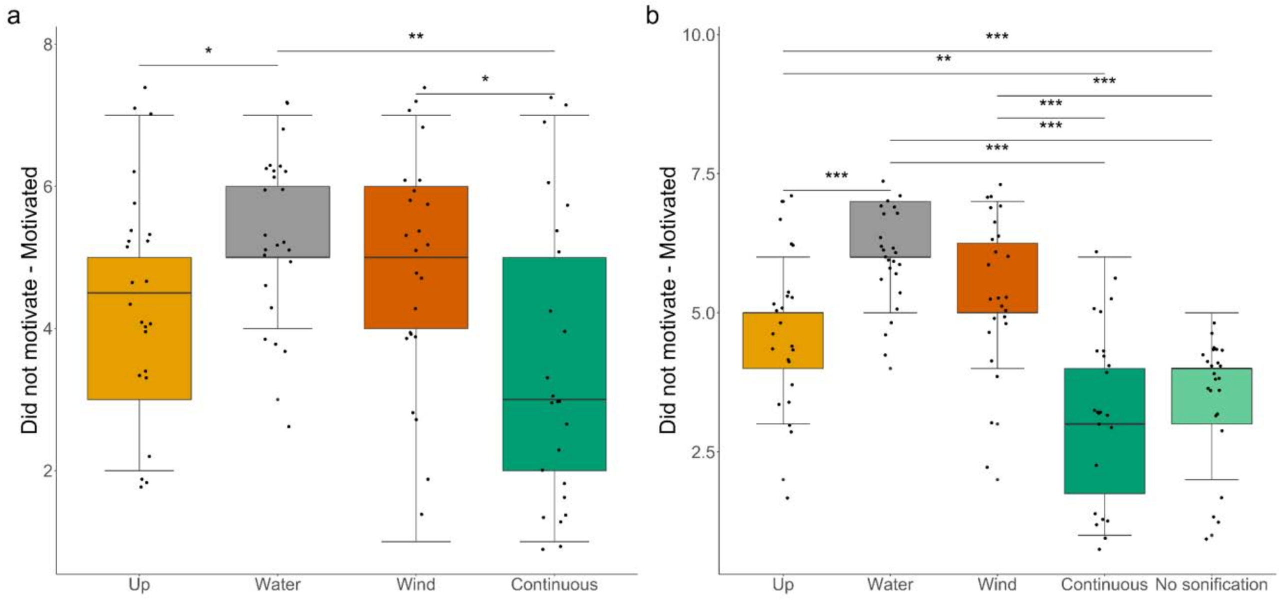


FIGURE 7.16: PERCEIVED MOTIVATION AS SHOWN BY RESULTS IN (A) QUESTIONNAIRE 1 AND (B) QUESTIONNAIRE 2 (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

j) Effects of sound condition on peak angle

The results of the item "*How much did you raise your leg"* included only in questionnaire 1, did not show significant differences between conditions ($X^2(4,24) = 7.013, p = .135$).

7.2.3.2. Effects of sound on "leg lift" movement behavior

The analyses of the movement data using repeated measures analyses of variance (ANOVA) showed significant effects between conditions for the parameters of mean angle, upward and downward time. Results for the mean angle ($F(4,84) = 2.673, p = .037, \eta 2 = .113$) showed that people reached higher mean angles with the "Continuous" sound ($t(21) = 2.880, p = .009, d = .614$), "Water" and "Wind" sound ($t(21) = -3.087, p = .006, d = .658$) than with the "No Sonification" condition, see FIGURE 7.17.

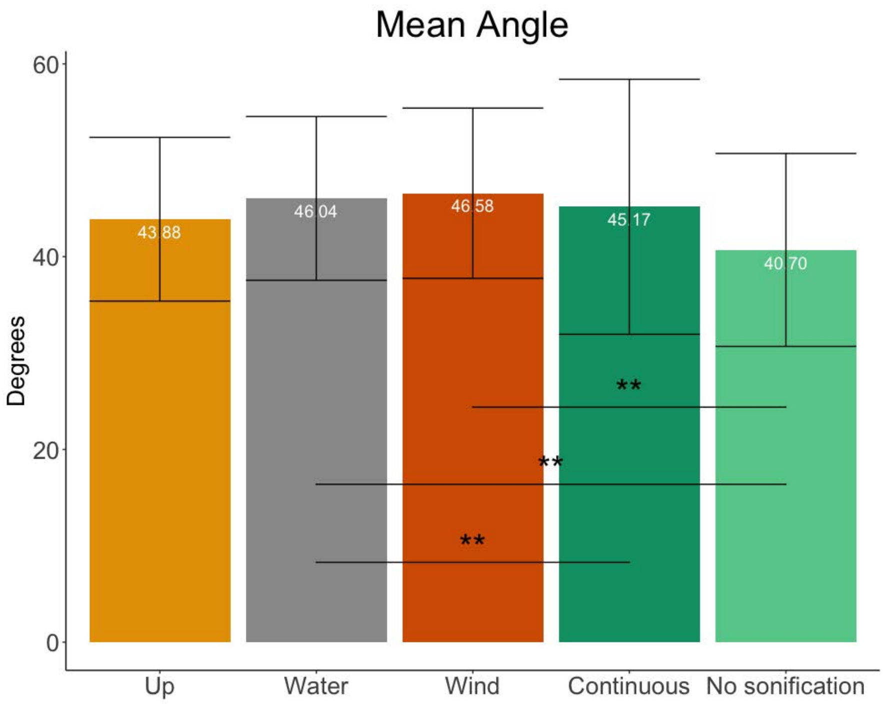


FIGURE 7.17: MEAN ANGLE BY CONDITION FOR THE "LEG LIFT" EXERCISE (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001).

Results for the upward time ($F(4,84) = 2.945, p = .025, \eta 2 = .123$) showed that participants spent more time lifting their leg with the "Continuous" sound ($t(21) = 2.259, p = .035, d = .481$), "Water" sound ($t(21) = -3.067, p = .006, d = .653$), and "Wind" sound ($t(21) = -2.633, p = .016, d = .561$), than with "No Sonification", see FIGURE 7.18a.

Results for the downward time ($F(4,84) = 4.137, p = .004, \eta 2 = .165$), showed that participants spent more time during the downwards movement with the "Water" sound ($t(22) = -2.287, p = .032, d = .475$) than with the "Continuous" sound. With "No Sonification", they spent less time during the downwards movement than with the "Wind" ($t(21) = -3.288, p = .004, d = .700$), "Water" ($t(21) = -3.318, p = .003, d = .707$), and "Up" ($t(21) = -2.281, p = .033, d = .486$) sounds, see FIGURE 7.18b.

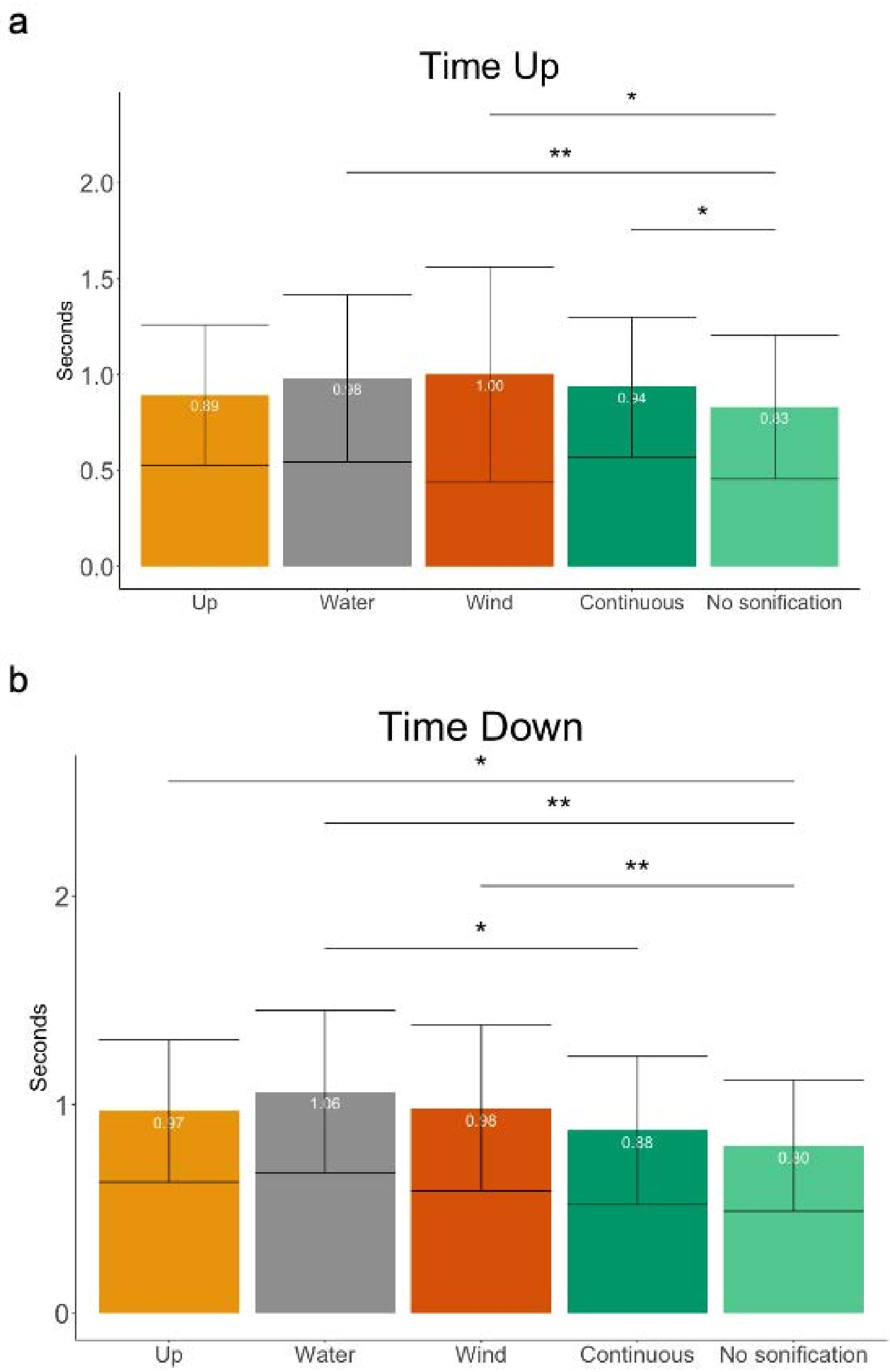


FIGURE 7.18: MEAN (A) UPWARD TIME AND (B) DOWNWARD TIME BY CONDITION FOR THE "LEG LIFT" EXERCISE (* INDICATES P < .05, ** INDICATES P < .01, *** INDICATES P < .001).

7.2.4. Conclusion

This section presented the quantitative findings from a controlled study that aimed to investigate the effects of different sonification conditions on perceived strength or the perception of being building muscles. This Chapter focused on a home-based “leg lift” exercise and investigated the effects of different movement sonifications. The effects of sound conditions on motivation and comfort, bodily feelings, and movement behavior were observed.

Results found that when participants listened to the “Water” sound with the exercise, they reported feeling **stronger** than when they were doing the exercise with the control condition (“Continuous” sound). This could be related to the fact that the “Water” sound made participants find the exercise **easier** than with the “Continuous”, “Wind” and “No Sonification” conditions. In addition, the sound of “Water” increased the sense of **agility** and of being **lighter** with respect to the “**No Sonification**” condition, and “Water” made participants feel their movements were more fluid than with the “Up” sound. Moreover, they felt **more capable** and that their movement **was more fluid** than with the “Continuous” sound. These results follow the previous findings in the “thigh stretch” experiment related to the body feelings, such as easiness, weight, or fluidity, elicited by the “Water” sound. Moreover, previous works using this sound, while not looking into whether the “Water” sound alters the perception of strength, showed that this sound helps to feel relaxed and motivated during the exercise [41]; or to guide in the start and end of movement [25], [39].

Further, the “Up” sound increases perceived **strength** as compared to the “No Sonification” condition. This may be due to the “Up” sound making participants feel more **capable** of performing the exercise than with the “Wind”, “No Sonification” and “Continuous” conditions. Moreover, participants perceived their leg was **lighter** with the “Up” sound than with the “Continuous” and “No Sonification” conditions. Moreover, the “Up” sound increased the sense of **agility** and made the exercise feel **easier** than with the “No Sonification” condition. It is worth mentioning that with the “Up” sound participants felt better proprioception of their leg than with the “Continuous” sound. However, the actual angle reached by participants was smaller for the “Up” sound. An alteration in proprioception awareness and a smaller angle during the movement could mean that participants perceived their foot reached the objective angle before it actually did and thus stopped the leg lift movement. Even though there were no significant differences in the peak angle of the actual movement between the “Up” and “Continuous” sound conditions, the average perceived angle was closer to the objective (90º, see TABLE 7.8) in the "Up" than in the "Continuous" sound condition. This effect in movement invites future work related to the influence of tones changing in pitch on proprioception [16], confidence in perceptual performance [160], or accuracy in the extremity position [161].

Lastly, the "Wind" sound made participants feel **stronger** than the "Continuous", "Up" and "No Sonification" conditions. Moreover, with the "Wind" sound the participants felt more **capable** of performing the exercise than with the "Continuous" and "No Sonification" conditions. Also, participants felt **lighter** with the "Wind" than with the "Continuous" and "No Sonification" conditions. Further, the "Wind" sound helped participants to feel their movement was more **fluid** and increased their sense of **agility** as compared to the "No Sonification" condition. These results show effects related to those observed in the previous study (Section 6.2.1.4) as well as in [126]; these studies reported that the "Wind" sound elicits bodily feelings of movement fluidity and energy put into the movement, which relate to the sense of capability and agility.

On the other hand, once participants had been exposed to all sound conditions and took time to reflect on them in the final questionnaire (i.e., questionnaire 2), results showed that participants still considered themselves stronger with "Water", "Wind", and "Up" sounds than with the other conditions. The "Wind" sound kept the sense of being stronger than the "Continuous" and "No Sonification" conditions. Lastly, participants felt stronger with the "Up" sound than with the "Continuous" sound.

In the final questionnaire participants also reported that the "Water" sound made them feel stronger than the "Continuous", "Up", and "No Sonification" conditions. At the same time, this questionnaire also highlighted that the participants felt their muscles worked harder with the "Water" than with the "Up" sound.

There was found significant differences in behavior: participants spent more time lifting their leg in the "Water", "Wind" and "Continuous" conditions, than in the "No Sonification" condition. Further, participants spent more time during the downwards movement with the "Water" sound than with the "Continuous" sound, which means that more force was applied when trying not to drop the leg. The opposite happens with "No Sonification": participants spent less time during the downwards movement than with the "Wind", "Water", and "Up" sounds, which means that less PA was implied, as participants let the leg fall. Previous results for the "thigh stretch" experiment showed that the

"Water" sound alters movement behavior, increasing the downwards acceleration as compared to all the other conditions. Meanwhile, with the same sound characteristics but a different movement (leg lift), the "Water" sound increased the time making participants apply more effort and force in their muscles. Hence, even when the sound characteristics could be the same it is still needed to explore and understand how a specific sound and movement could work together.

It is worth mentioning that in terms of motivation, participants felt more motivated to do the exercise with the "Wind" sound than with the "Continuous" sound and the "No Sonification" condition. Moreover, they also felt more motivated with the "Water" than with the "Up" and "Continuous" sounds. This could be related to participants reaching higher mean angles with "Water" and "Wind" sounds, as well as with the control condition, than with the "No Sonification": feeling more motivated with these sounds seems to prompt participants to reach a higher angle. For the final questionnaire, the "Water" sound motivated more participants than the "Up", "Continuous", and "No Sonification" conditions. Lastly, participants perceived themselves as more motivated with the "Up" sound than with the "Continuous" and with the "No Sonification" conditions.

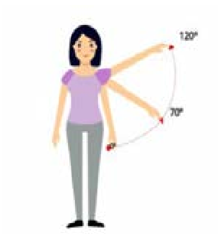
7.3. Study 3: to evaluate the effect of spatial metaphors in proprioception

This section presents three experiments in which participants were asked to raise their right arm to reach one out of two pre-trained positions. The effects of different sounds were evaluated on participants' bodily movement (i.e., lifting amplitude, velocity, acceleration, time) and on their proprioceptive awareness, measured in terms of accuracy of final arm position (i.e., elevation angle of the arm), as well as on the confidence on having reached that position, as changes in pitch may lead to the illusion of vertical displacement of one's arm as if this was being "pulled up" or "pushed down" by the sound [16], [59], [159]. The effects on body-representations in terms of subjective feelings about one's body (e.g., lightness, strength) and the movement (e.g., movement ease, capability to perform the movement) were further investigated, as well as the effects on the emotional state which may accompany these changes.

Based on the findings of the previous studies, this thesis was interested in seeing whether a change in pitch played a pivotal role in explaining the bodily effects of sounds listened during body movement or any forms of PA, through a multisensory binding analogous to the one found in other proprioceptive illusions such as the rubber hand illusion [14]. The previous literature on multisensory bodily illusions [15], [16], [34], [55] gives us good reasons to expect that pitch change would affect all three aspects of motion, bodily awareness, and bodily feelings in specific ways (see TABLE 7.9), but each experiment enables us to address additional questions. **Experiment 1** could compare whether the changes in movement, proprioceptive awareness, and bodily feelings would all be equally sensitive to the congruence between pitch and motion direction. **Experiment 2** could assess whether and how a richer musical timbre (i.e., a richer spectrum with several harmonics and dynamic changes in loudness) would enhance, diminish the effect of pitch on movement, awareness and bodily feelings, or influence them in other manners. Because harmonics are shown to be overall more pleasant to listen to, an increase in the bodily feelings, in the positive direction, but not in the other effects were expected. However, if cross-modal correspondences between pitch and upward/downward space are emotionally mediated [162]; see also [163], [164] for reviews) then a more general increase in all three effects could also be seen. In addition, because the dynamic changes in loudness often present in music interact with the perception of pitch [165]–[168], and can also elicit impressions of changes in spatial distance [169], [170] a richer musical timbre may modulate (either maximize or diminish) the effects observed for pure tones.

Finally, **Experiment 3** could assess whether the relative direction of pitch change was all that mattered, or whether the absolute frequency range also modulated and explained the effects. Here the literature on cross-modal correspondences (see [171]) gives us reasons to predict that the relative change was all that mattered, notably for more automatic effects on motion and proprioception; for instance, in terms of mapping with changes in spatial elevation, the absolute frequency range is less significant than the direction of the frequency change [172]. But other previous results (see TABLE 7.9) made us expect that the absolute frequency range would affect bodily feelings, with higher frequencies making people, for instance, feel significantly lighter than lower frequencies [17], [33].

TABLE 7.9: SPECIFIC PREDICTIONS/REPLICATIONS FOR THE ROBUST EFFECT OF PITCH CHANGES ACROSS ALL THE EXPERIMENTS.

Dimension	Predicted effects of raising vs. descending pitch	Effects reported in previous literature (Reference)
Bodily movement 	Movement parameters: A sound increasing or decreasing in pitch accompanying the participant's arm movement will respectively increase/decrease participants' arm vertical movement amplitude and its acceleration/velocity, as if the sound would "pull up"/ "push down" the body.	**Perceptions of motion for objects outside the body:** Dynamic changes in pitch elicit perceptions of changes in height, size, and motion along the vertical plane ([173]; see review by [174]). Associations of tonal sounds rising in pitch with motion upwards have been also found in gestural depictions of sounds [175]. **Effects of harmonic content (stability of musical sounds) on bodily movement:** Musically resolved (i.e., ending on a perfect or harmonically stable cadence) vs. unresolved (i.e., ending on an imperfect or harmonically unstable cadence) sonifications accompanying arm raise movements lead people to increase the movement amplitude and stretch for longer, potentially due to musical expectation [176] . **Effects of frequency range on bodily movement:** Shifting the pitch of walking sounds to make the sounds consistent with having a heavier or lighter body results in changes in the leg movement acceleration and stance time [17], [33].
Proprioceptive awareness 	Accuracy of and confidence in perceived final position: A sound increasing or decreasing in pitch accompanying the participant's arm movement will lead participants to be less accurate and become less confident about their arm position, as a result of sound interfering with proprioception.	**Sound influence on the accuracy of perceived object position:** This is illustrated by literature on the ventriloquism illusion, by which people mislocalize the source of speech sounds when incongruent visual cues are synchronously presented (e.g., [161]). **Sound influence on confidence in perceptual performance:** Literature on the McGurk effect [177], by which people misperceive incongruent visual and auditory cues, shows not only a decrease in perceptual accuracy, but also effects on the subjective confidence in perceptual performance [160]. **Illusory body extension potentially driven by sound influences on proprioception:** When brief sounds rising in pitch are paired and presented synchronously with the action of oneself pulling on one's occluded fingertip can lead to participants feel and estimate their finger to be longer [16] suggesting influences of sound on proprioception. This illusion was replicated both in adults and pre-school children for passive finger pulling [63]. **Influence of harmonic stability of musical sounds on perceived body position:** Musically resolved or

		unresolved sonifications accompanying squat movements impact on the perceived depth of the squat [178]. **Influence of movement sonification on movement variability:** Movement sonification can induce higher movement variability for both musicians and non-musicians when starting to learn a new movement sequence, while it is reduced later when the movement is mastered. It has been hypothesized that the sound feedback provokes a change of attentional focus that perturbates proprioceptive awareness [179].
Bodily and emotional feelings 	Feelings about one's body, the movement, and emotional state: A sound increasing or decreasing in pitch accompanying the participant's arm movement will impact on how people feel "about their body" (e.g., weight or speed) and "about their movement" (e.g., ease, comfort). Sounds increasing vs. decreasing in pitch will enhance the emotional state, making people feel happier, more excited and motivated.	**Perceptions of size for objects outside the body:** Pitch is associated to physical size; static high and low pitches are respectively congruent with smaller and larger sizes [180]–[184]. **Effect of pitch (frequency range) on perceived body size and feelings:** Shifting the pitch of walking sounds to higher frequencies makes people experience their body as being slimmer and lighter than usual, as well as quicker and happier, while the opposite is true for lower pitch sounds [17]. With high-frequency footsteps sounds people find step-up exercises less difficult and feel less tired [33]. Effects of change on pitch on bodily and emotional feelings: -In a qualitative study people reported that a sound rising in pitch paired with bodily movement induces pleasantness and feelings of movement fluidity and body lightness and flexibility [185]. -Sequences of tonal beeps or notes changing in musical pitch and sonifying trunk movement during forward reach exercises help to build confidence and motivate people with chronic pain to move despite pain and fear of injury [27], [41], [108]. **-Effects of harmonic content*:*** Musically resolved sonifications accompanying stretching and squat movements increase feelings of reward and achievement, as well as motivation to continue the movement [22], [25], [112], [176].

7.3.1. Author contributions and related publication

In this study, I was responsible for the recruitment, acquisition, and analysis of the data of Experiments 1 and 2. For these two experiments, I contributed to the conception and design of the work; the development of the sonification mappings, the software, and hardware for such movement sonification and data acquisition. In Experiment 3, I collaborated in the conception and design of the work, the development of mappings, and the analysis of the data. Finally, I was responsible for the writing of the methods and results sections of the three experiments with supervision from other senior researchers from the research team.

These experiments have been published in the form of a journal paper and as part of a master thesis.

In this paper, the introduction and discussion sections were written by senior researchers with these thesis contributions. The full reference of the paper is:

> *Ley-Flores, J.*, Alshami, E., Singh, A. et al. Effects of pitch and musical sounds on body-representations when moving with sound. Scientific Report 12, 2676 (2022). https://doi.org/10.1038/s41598-022-06210-x

The full reference of the master thesis is:

> Alshami, E. The Effect of Audio Pitch and Direction on Emotional State, Bodily Perceptions and Movement During Sonified Arm Raises. University College London (2020).

7.3.2. Methods: Experiment 1. Effects of pitch change (Sound Direction)

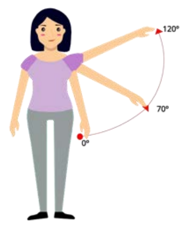
7.3.2.1. Participants and setting

Twenty-five participants took part (M_{age}= 27.68, SD_{age}= 5.83, Range= 20 – 39; n=25; 11 females, 14 male). In all experiments reported here, participants gave their informed consent prior to their inclusion in the studies and the study was conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Experiments 1 and 2 were approved by the local ethics committee at Universidad Carlos III de Madrid (UC3M, Appendix K). The same participants took part in Experiments 1 and 2, and they received a compensation of 10 euros for their participation in both experiments. Participants took part in Experiment 2 after having completed Experiment 1.

Exercise

A "side arm raise" exercise was chosen, as this is a basic exercise that involves the challenge of raising the arm to different angles and strengthening the upper arms (see TABLE 7.10). This gesture is part of many dance sequences, and it is also an exercise that is part of the general warm-up or toning routines of many programs or guidelines oriented toward dance or general PA, for instance, guidelines for becoming more physically active [140], [186].

TABLE 7.10: DESCRIPTION OF THE “SIDE ARM RAISE” EXERCISES.

Exercises	Description	Example	
		Trajectory -----	
		Start position •	Objective ➤
Side arm raise	**Initial Position:** Stand with your arms extended beside your legs (0 degrees).		
	Trajectory: raise the right arm (mirror image) until the arm reaches the angle of 70 or 120 degrees.		
	Objective (raising): Hold the arm up for 1 second.		

7.3.2.2. Apparatus and stimuli

a) SoniBand: desktop version

The SoniBand prototype was used, based on [141], [187], see Section 5.2.3. This is a wearable self-locking band equipped with a hand-sewn cloth pocket containing a wireless emitter (BITalino R-IoT embedding a 9-axis Inertial Motion Unit (IMU) digitized at 16 bits). The band wirelessly transmits data through Wi-Fi using the OSC protocol to a computer running Max/MSP (Cycling’74)[10] and can detect the start of the movement and trigger then a sound to accompany the movement (i.e., sonification). The device is calibrated to the range of movement to be sonified for a specific person through a graphical user interface. To do so, the configuration of the arm at the start (minimum movement angle) and at the end of the movement (maximum movement angle) are registered. The software also records the movement data for posterior off-line analysis. The sound was fed back to participants through wired headphones (Sennheiser HD 2.30G).

b) “Side arm movement”: sound stimuli

Three auditory stimuli were used, drawing on previous studies by [16], [63]. They consisted of pure tones (1300-ms duration and 44.1-kHz sample rate) with ascending (“Tone_up”, 600 to 1200 Hz), descending (“Tone_down” 1200 to 600 Hz), or constant (“Tone_constant”, 600 Hz) frequency (see FIGURE 7.19). The pitch change occurs during 500 ms, followed by a sustained part of 500 ms, and decay of 300 ms. Note that the frequency range employed slightly differed from the one used by [16]

[10] https://cycling74.com/

(i.e., 700-1200 Hz). The choice of 600 Hz, instead of 700 Hz, was made to ensure a full octave in the ascending and descending sounds, providing a target sound that appears natural from a musical point of view as going up or down a full scale. Further, note that the constant sound was included as a "control" or reference condition with which to compare the effect of the sounds changing in pitch, such as in [16], [63]. This was preferred to a "no sound" condition, as it allowed controlling for the effect of simply listening to a sound; see other studies using a similar control condition (see previous studies in Chapter 7, [170], [185]).

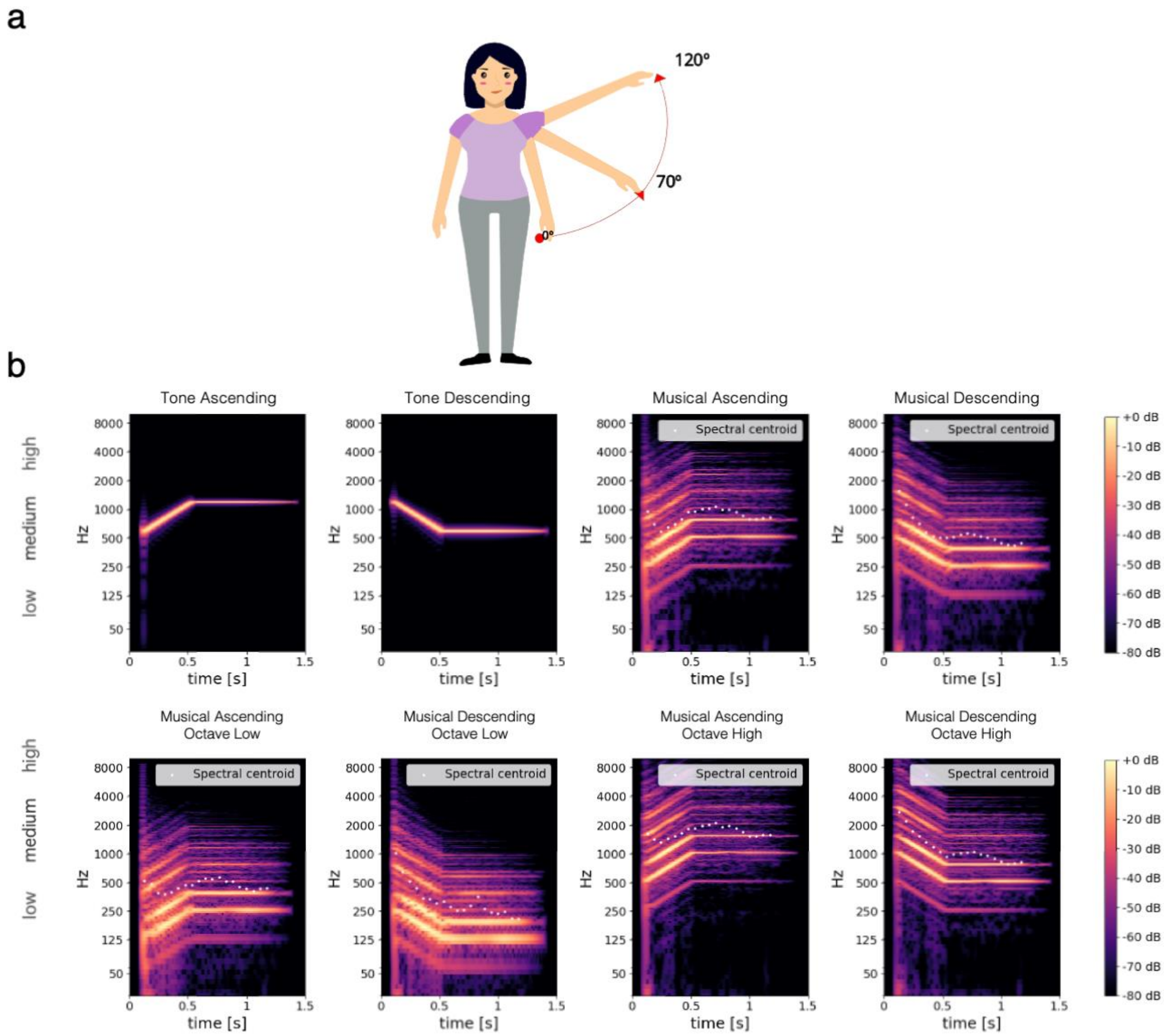


FIGURE 7.19: SIDE ARM RAISE MOVEMENT, GRAPHICAL REPRESENTATION OF THE EXPERIMENTAL PROCEDURE AND SPECTRA OF THE DIFFERENT TONES AND MUSICAL SOUNDS USED IN THE EXPERIMENTS. (A) ACROSS CONDITIONS, PARTICIPANTS WERE REQUESTED TO RAISE THEIR ARM FROM 0º TO 70º (POSITION 1) OR FROM 0º TO 120º (POSITION 2). (B) THE DIFFERENT PLOTS FROM TOP-LEFT TO BOTTOM-RIGHT CORRESPOND TO THE FOLLOWING STIMULI: "TONE_UP", "TONE_DOWN", "MUSICAL_UP", "MUSICAL_ DOWN", "MUSICAL_UP_LOW_PITCH", "MUSICAL_DOWN_LOW_PITCH",

“MUSICAL_UP_HIGH_PITCH”, “MUSICAL_DOWN_HIGH_ PITCH” (SEE THE SUMMARY OF EXPERIMENTAL CONDITIONS AND FACTORS STUDIED WITH THESE SOUNDS IN TABLE 7.11).

7.3.2.3. Measures

To monitor changes in bodily movement, task confidence (i.e., confidence in perceived final position, related to sound influences in proprioceptive awareness), bodily and emotional feelings across the different sound conditions the following measures were used:

a) Questionnaire data:

Task confidence (Confidence in perceived final position): Explicit confidence (or certainty judgments) allows us to assess the reliability of perception across different decisions (e.g., [188]); it relates to subjective estimates of being right rather than objective accuracy, and therefore falls within the field of metacognition. To assess the participants’ confidence in the perceived final position, section 1 in the survey included a question about confidence reaching the requested position (i.e., position 1 or 2), “How confident were you with this sound that your arm was in the <position>?”, which was based on previous research assessing task confidence [188]–[190]. Participants answered using a 7-point Likert-type scale, ranging from 1: “not confident at all” to 7: “completely confident”.

Bodily and emotional feelings: survey section 2 included 9 items (7-point Likert-type) and was developed based on the questionnaires used in related studies [17], [33] (Appendix L).

Three items related to how people feel about their body during the exercise - they began with “As I was doing the exercise, I felt...” and then ranged from:

- “Light” (1) to “Heavy” (7), **Weight**
- “Slow” (1) to “Quick” (7), **Speed**
- “Not tired” (1) to “Tired” (7), **Tiredness**.
- Four items related to their feelings about the movement and the endurance to perform the exercise: “As I was doing the exercise, I felt...” then ranged from
- “Not in control” (1) to “In control” (7), **Control**
- “Uncomfortable” (1) to “Comfortable” (7), **Comfort**
- “With this sound the exercise was…” then ranged from “Easy” (1) to “Difficult” (7), **Difficulty**
- “I felt” then ranged from “Incapable” (1) to “Capable of performing the exercise” (7), **Capability**

- ○ Another item assessed the emotional effects of the sounds heard on motivation to do the exercise: from "Did not motivate" (1) to "Motivated me to do the exercise" (7), **Motivation**
- ○ Finally, an item related to felt agency over the heard sounds was included (ranging from "Not produced" (1) to "Produced by me" (7), **Agency**

As previous studies have shown that if the agency is disrupted (for instance, due to large discrepancies between modalities or delays between actions and sensory feedback) then sensory-induced body effects diminish (e.g., [15], [60]). Note that the repartition of items into the different categories (e.g., feelings about the body or feelings about the movement) was not made explicit to participants, and it is presented like this here to facilitate the assimilation of effects; some of the items could fall into two categories (e.g., "I felt uncomfortable" might be interpreted relative to the movement itself, or more generally about the body).

b) Behavioral data:

The movement sensor data were used to quantify changes in the reached angle and in the movement dynamics (time, velocity, acceleration). In particular, the following parameters were extracted using MATLAB software: maximum (peak) and mean angle; time from minimum to maximum position (time up) and from maximum to minimum position (time down); mean angular velocity from minimum to maximum position (velocity up) and from maximum to minimum position (velocity down); and maximum linear acceleration from minimum to maximum position (acc up) and from maximum to minimum position (acc down).

7.3.2.4. Experimental procedure

The experiment was conducted in a quiet room and consisted of four phases: calibration, training, experiment, and questionnaires, as detailed below (see FIGURE 7.20). The full procedure took approximately 25 minutes.

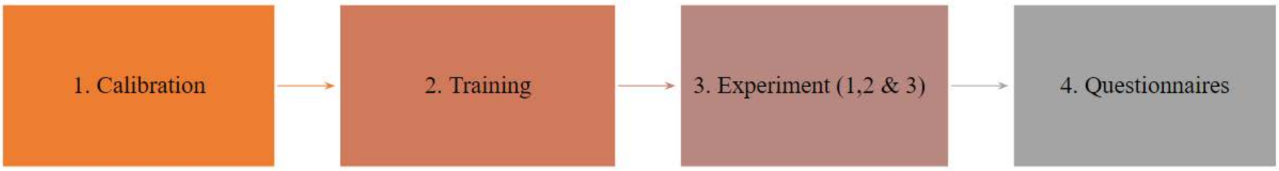


FIGURE 7.20: THE EXPERIMENTAL PROCEDURE CONSISTED OF FOUR PHASES: CALIBRATION, TRAINING, EXPERIMENT (WITH BEHAVIORAL DATA ACQUISITION), AND QUESTIONNAIRES.

Calibration: Firstly, participants were asked to stand with their back against a whiteboard. Secondly, the experimenter drew on the whiteboard a point at shoulder height while the participants held her right arm in a soldier's position (this was marked as the movement start position i.e., angle of 0º). Thirdly, three lines were drawn to indicate the initial position (angle of 0º) and the angles of 70º and 120º that indicate position 1 and 2 respectively during the experiments (See FIGURE 7.19a and TABLE 7.10). Note that two positions, rather than only one (as in (Bourdin et al., 2019)), were chosen to avoid habituation and increase participants' concentration on their perceptions of their hand position. The position of the arm at 0º (minimum movement angle) and 120º (maximum movement angle) were registered by the Max/MSP software respectively with the values 0 and 1. This calibration was performed in order for the software to recognize these positions and to trigger a sound in the experimental trials when identifying that the arm left the minimum movement angle (i.e., the 0º position).

Training: Participants were asked to lift their arms laterally five times to position 1 and five times to position 2, in the order indicated by the experimenter, and with their eyes opened. This allowed participants to practice their arm movement to reach both positions. Participants were then asked to close their eyes and lift their arms laterally five times to position 1 and five times to position 2, in the order indicated by the experimenter. No feedback sound was delivered. Further, the experimenter did not provide any feedback to participants on their performance.

Experiment: Participants were told that in each trial, with their eyes closed, they would be asked to lift their arm laterally to reach either position 1 or position 2, as indicated verbally by the experimenter at the start of the trial, as in the training phase. Once participants were indicated the target position, they initiated the movement when they felt like and their movement onset triggered a sound that was irrelevant to the task (i.e., stimuli were not time-locked to the experimenter instruction, but to participants' movement onset). In each trial, participants listened to one of the three sounds ("Tone_up", "Tone_down", or "Tone_constant"). Note that even if participants returned to the start position after each arm raise, the sound was only triggered by the upwards movement. Each sound was presented ten times (as in [16]), five times per position (30 arm lifts in total). The different combinations of sounds and positions were presented randomly to minimize order bias. See "TABLE 7.11, Summary of the experimental conditions".

Questionnaire: At the end of the 30 experiment trials, participants were asked to repeat the arm lift task while listening to a tone for six more trials, two trials for each sound condition, and to complete a questionnaire for each sound condition (similarly to the procedure followed in [16]). For each sound condition, participants repeated two arm lift trials, of which one trial corresponded to Position 1 and the other trial to Position 2, with the presentation order randomized across participants. After each arm lift, participants were asked how confident they were of having reached the requested position with the current sound (Survey section 1 - Confidence). Participants were then asked to complete a self-report of their body feelings when performing the task with that sound (Survey section 2 - Body feelings). Participants repeated the survey procedure for the three sound conditions (their order presentation was randomized).

TABLE 7.11: SUMMARY OF THE EXPERIMENTAL CONDITIONS (ORDERED RANDOMLY), FACTORS AND NUMBER OF REPETITIONS AND TRIALS IN EXPERIMENTS 1, 2, AND 3.

<table>
<tr><th>Experiment</th><th>Sound Condition</th><th>Sound Direction</th><th>Sound Timbre</th><th>Sound Frequency Range</th><th>Repetitions / Total nr. trials</th></tr>
<tr><td rowspan="3">Experiment 1</td><td>Tone_constant</td><td>Constant</td><td rowspan="3">Tone</td><td rowspan="3">Medium</td><td rowspan="3">10 per condition (5 per position) / 30</td></tr>
<tr><td>Tone_up</td><td>Up</td></tr>
<tr><td>Tone_down</td><td>Down</td></tr>
<tr><td rowspan="4">Experiment 2</td><td>Tone_up</td><td>Up</td><td rowspan="2">Tone</td><td rowspan="4">Medium</td><td rowspan="4">10 per condition (5 per position) / 40</td></tr>
<tr><td>Tone_down</td><td>Down</td></tr>
<tr><td>Musical_up</td><td>Up</td><td rowspan="2">Musical sound</td></tr>
<tr><td>Musical_down</td><td>Down</td></tr>
<tr><td rowspan="4">Experiment 3</td><td>Musical_up_Low_pitch</td><td>Up</td><td rowspan="4">Musical sound</td><td>Low-Medium</td><td rowspan="4">10 per condition / 40</td></tr>
<tr><td>Musical_down_Low_pitch</td><td>Down</td><td>Medium-Low</td></tr>
<tr><td>Musical_up_High_pitch</td><td>Up</td><td>Medium-High</td></tr>
<tr><td>Musical_down_High_pitch</td><td>Down</td><td>High-Medium</td></tr>
</table>

7.3.2.5. Data analysis

For movement data, for each of the parameters extracted data were first analyzed with separate repeated-Measures 3x2x5 analyses of variance (ANOVAs), suitable for continuous normal data, with within-subject factors Sound Direction (Ascending, Descending or Constant), Position (1 or 2), and Repetition (1 to 5). Given that there was no significant effect of the factor Repetition or interaction of Repetition with the other factors, data from the 5 repetitions for each condition were averaged and

3x2 ANOVAs were run with the factors Sound Direction and Position. Significant effects were followed by paired t-tests comparing the means obtained for the different conditions, which were corrected for multiple comparisons with the recommended Tukey method for comparing a family of estimates [191].

For questionnaire data, to investigate the task confidence data the interaction between the factors Sound Direction (Ascending, Descending or Constant) and Position (1 or 2), non-parametric ANOVAs on aligned rank transform (ART) data was conducted, suitable for ordinal data, using the R package ARTool [191]. Running ANOVAs allowed investigating the interaction between the factors Sound Direction and Position. For the data on Bodily and Emotional Feelings, non-parametric ANOVAs on ART data with a single within-subject factor, Sound Direction was conducted. Significant main effects were followed by paired t-tests on the ART data, which were corrected for multiple comparisons (Tukey method). In addition, to compare self-reported confidence in the position with the actual task performance (i.e., measured position), Spearman correlation analyses was conducted for each of the conditions between the maximum angle (average of all repetitions for the condition) and the task confidence rating provided by the participants for that condition. All the statistical significance were with the corresponding effect size statistic: Partial eta-square ($\eta 2$, large effect is .14, a medium effect is .06, and a small effect is .01 or higher) and Cohen's d (large effect is .8, a medium effect is .5, and a small effect is .2) for paired sample t-tests by using the libraries "ARTool", "Emmeans", and "Car"[11].

7.3.3. Methods: Experiment 2. Effects of harmonic content (Sound Direction and Timbre)

7.3.3.1. Participants and setting App

Same participants that took part in Experiment 1. All participants performed Experiment 2 after having completed Experiment 1.

Exercise

Same as in Experiment 1

[11] https://cran.r-project.org/web/packages/ARTool/vignettes/art-effect-size.html

7.3.3.2. Apparatus and stimuli Measures

a) SoniBand: desktop version

Same as in Experiment 1.

b) "Side arm movement": sound stimuli

Four auditory stimuli were used. Two of the stimuli were 'Tone_up' and 'Tone_down' sounds employed in Experiment 1. The Tones were created using a single frequency whose pitch is varied one octave up or down (i.e., frequency being multiplied or divided by 2, respectively), as shown in FIGURE 7.19b. The pitch change occurs during 500 ms, followed by a sustained part of 500 ms, and a decay of 300 ms. The other two stimuli consisted of musical sounds, "Musical_up" and "Musical_down", designed with the same duration and pitch variation of one octave up or down, based on (Ley-Flores et al., 2019). For both the Tone and Musical Sounds, the pitch change occurs during the first 500 ms, and then remains constant for 1s (see FIGURE 7.19b).

While the Tone sound spectrum is formed by a single frequency (sometimes referred as "pure" sound), the Musical Sound exhibits a rich spectrum and more complex energy envelope, formed by an attack (peak at 200 ms, followed by a decay (300 ms), sustained part (500 ms), and release (300 ms). The Musical Sound is made of two notes, a fifth interval (e.g., C-G) that is considered in music theory as consonant and neutral [192]. While a single musical note could have been used, the choice of the consonant fifth interval was motivated to produce a higher contrast to the pure tone in terms of spectral richness, without adding any musical tension from a perception point of view. As shown in FIGURE 7.19b, the musical sound spectrum is formed by several harmonics that span from 130 Hz to more than 6000Hz. Importantly, the spectral centroid of the Musical Sound is comparable to the Tone frequency range (600-1200 Hz).

In summary, the main differences between the Tones and Musical Sounds reside in 1) the sound timbre given by the spectrum structure (harmonic content) and 2) the audio energy temporal envelope, with a stronger attack for the Musical Sound.

7.3.3.3. Measures

Same as in Experiment 1 (Appendix M).

7.3.3.4. Experimental procedure

Calibration and training phases were identical to those in Experiment 1. The experiment and questionnaire phases differed in that there were four instead of three sound conditions. In the experiment phase, each sound was presented ten times, five per position, as in Experiment 1 (40 arm lifts in total). The sounds were randomly ordered to minimize order bias. The full procedure took approximately 25 minutes.

7.3.3.5. Data Analysis

For **movement data**, for each of the parameters extracted data were analyzed by conducting separate 2x2x2x5 ANOVAS with within-subject factors Sound Direction (ascending, descending), Timbre (Tone, Musical), Position (1 or 2), and Repetition (1 to 5). As in Experiment 1, there was no significant effect of the factor Repetition or interaction with the other factors. Therefore, data from the 5 repetitions for each condition were averaged and ANOVAs were run with the factors Sound Direction, Timbre and Position. Significant effects were followed by paired t-tests, which were corrected for multiple comparisons (Tukey method). Lastly, complemented with the corresponding effect size, Partial eta-square ($\eta 2$, large effect is .14, a medium effect is .06, and a small effect is .01 or higher) directly obtained from [193].

For **questionnaire data**, to investigate the interaction between the factors Sound Direction (Ascending, Descending) and Timbre (Tone, Musical), non-parametric ANOVAs on ART data using ARTool were conducted. For the data on Task confidence, an additional factor of Position (1 or 2) was added to the ANOVAs. Significant interactions between factors were followed by interaction contrasts, which look at differences of differences, using the "testInteractions" function [194], [195], which is part of the R "Phia" module. The Holm method for p-value adjustment was used, as recommended.

As in Experiment 1, Spearman correlation analyses were conducted for each of the conditions between the maximum angle (average of all repetitions for the condition) and the task confidence rating provided by the participants for that condition.

7.3.4. Methods: Experiment 3. Effects of absolute frequency range (Sound Direction and Sound Frequency Range)

7.3.4.1. Participants and setting

Twenty participants took part (M_{age}= 25.1, SD_{age}= 3.13, Range= 22-34; n=9 females, 11 male). Experiment 3 was approved by the local ethics committees at UC3M and at University College London (Appendix N). Participants took part in exchange for a raffle, giving them an opportunity to win one of several Amazon vouchers (£30x3, £10x6).

Exercise

Same as in Experiments 1 and 2, with the only difference that participants were asked to raise their arm until it reached a horizontal position (an angle of 90º, as in [196]). Note that, differently from Experiments 1 and 2, only one position was employed to reduce the experimental length due to time restrictions.

7.3.4.2. Apparatus and stimuli

a) Go-with-the-Flow-Moves@HOME: mobile version

Due to the Covid-19 Lockdown, participants were asked to use their own headphones and their own Android phones with a software application (Go-with-the-Flow-Moves@HOME, supporting Android 6.0 and superior versions) developed for research purposes. The design of the application was based on [41]. Using the accelerometer and gyroscope sensors, the application can detect the movement and calibrate the mobile to the range of the movement, similarly as in Experiment 1 and 2. Wearable arm straps were provided through postal services. Microsoft Teams software was used for the Experimenter to guide and interact with participants, closely monitoring the experiment. A Qualtrics survey was used to record responses to Likert-type questionnaire items.

b) "Side arm movement": sound stimuli

Four auditory stimuli were used to explore the effect of the baseline pitch on actual and perceived motion (see FIGURE 7.19b). These were variations of the "Musical_up" and "Musical_down" sounds employed in Experiment 2, in which the sound frequency range was shifted either one octave up or one octave down, as described here: "Musical_up" pitch shifted one octave down ("Musical_up_Low_pitch"), "Musical_up" pitch shifted one octave up ("Musical_up_High_pitch"), "Musical_down" pitch shifted one octave down ("Musical_down_Low_pitch"), "Musical_down" pitch shifted one octave up ("Musical_down_High_pitch").

7.3.4.3. Measures

As in Experiments 1 and 2, self-report and behavioral measures were collected to monitor changes across the different sound conditions. Note that, differently from Experiments 1 and 2, to reduce the experimental length due to time restrictions task confidence was not assessed, but additional items were added to the survey which allowed to further investigate the effects on bodily and emotional feelings.

a) Questionnaire data:

Bodily and emotional feelings: A survey (Appendix O) with 13 items (Likert-type) was used to investigate how each sound affects the emotional and bodily feelings of participants during the lateral arm raises. The first 2 items corresponded with the two Self-Assessment Manikin graphical scales (9-point Likert-type response items) for valence and arousal [152]. Participants were asked to "select the figure that best represents how you felt during the single arm raise experience". The items ranged from:

- "Unhappy, Negative" (1) to "Happy, Positive" (9), **Valence**
- "Unaroused, Calm" (1) to "Aroused, Excited" (9), **Arousal**.

The remaining items were 7-point Likert-type response items. 9 items were the same as those included in the survey in Experiments 1 and 2; the 2 additional items were the following: first item began with "As I was doing the exercise, I felt..." and then ranged from:

- "Weak" (1) to "Strong" (7), **Strength**.

The second item began with "As I was doing the exercise, I felt my movement was…:" and then ranged from:

- "Uncoordinated" (1) to "Coordinated" (7), **Coordination**.

b) Behavioral data:

The movement sensor data recorded by the app were used to quantify changes in the maximum reached angle (peak angle) and in the movement dynamics (time, velocity, acceleration) of the upwards movement. Same parameters as in Experiments 1 and 2 (except for movement dynamics of the downwards movement, due to the app only tracking the upwards movement) were extracted using MATLAB software.

7.3.4.4. Experimental procedure

Participants were asked to be in a quiet room at home and to stand up during the experiment. No training or baseline phases were used. Participants were asked to raise their arms laterally to a 90º position while listening to one of four sounds ("Musical_up_Low_pitch", "Musical_up_High_pitch", "Musical_down_Low_pitch", "Musical_down_High_pitch"). As in Experiments 1 and 2, the sound was only triggered by the upwards movement. Each sound was presented ten times (40 arm lifts in total). The sounds were randomly ordered to minimize order bias (See TABLE 7.11. Summary of the experimental procedure). At the end of the 40 experiment trials, participants were asked to repeat four additional arm lift trials, one for each sound condition, and after each sound presentation, they filled in an online survey with 13 items asking about emotion and body feelings when performing the task with that sound. This survey is detailed in the Measure section. The full procedure took approximately 40 minutes.

7.3.4.5. Data Analysis

For movement data, for each of the parameters extracted data were analyzed by conducting separate 2x2x10 ANOVAS with within-subject factors Sound Direction (Ascending, Descending), Sound Frequency Range (High, Low), and Repetition (1 to 10). As in Experiments 1 and 2, there was no significant effect of the factor Repetition or interaction with the other factors. Therefore, data from the 10 repetitions for each condition were averaged and only the factors Sound Direction and Sound Frequency Range were considered in the analyses. Significant effects were followed by paired t-tests, which were corrected for multiple comparisons (Tukey method).

For questionnaire data, to investigate the interaction between the factors of Sound Direction (Ascending or Descending) and Sound Frequency Range (High or Low), non-parametric ANOVAs on ART data using the "ARTool" package were conducted. Significant main effects were followed by paired t-tests, which were corrected for multiple comparisons (Tukey method).

7.3.5. Results

The next three sections describe the sound effects on bodily movement, proprioceptive awareness (task confidence and position accuracy), and bodily and emotional feelings observed across the three experiments. TABLE 7.12 at the end of the results section summarizes all findings.

7.3.5.1. Experiment 1. Effects of pitch change (Sound Direction)

a) Effects on bodily movement

The analyses of the movement data showed a significant effect of the factor Position for most of the extracted parameters. As expected, for the condition where participants were asked to reach Position 2, the mean angle ($F(1,24) = 217.83, p < .001, \eta 2 = .90$) and maximum angle ($F(1,24) = 222.76, p < .001, \eta 2 = .90$) were higher. This effect of position was also reflected in longer "time down" ($F(1,24) = 21.34, p < .001, \eta 2 = .47$), higher "velocity up" ($F(1,24) = 148.70, p < .001, \eta 2 = .86$) and higher "velocity down" ($F(1,24) = 57.32, p < .001, \eta 2 = .70$), higher "acceleration up" ($F(1,24) = 67.49, p < .001, \eta 2 = .74$), and higher "acceleration down" ($F(1,24) = 70.47, p < .001, \eta 2 = .75$) for Position 2 than for Position 1.

There were no significant effects of Sound Direction or interaction between Sound Direction and Position for any of the analyzed parameters. There was observed a substantial though non-significant effect of Sound Direction for "time down" ($F(2,48) = 2.41, p = .100, \eta 2 = .09$): participants took longer to return to the initial position with the "Ascending" sound, though the effect did not reach significance (Constant: *M* = 2.85 sec, *SD* = 0.94; Tone-up: *M* = 3.01 sec, *SD* = 1.26; Tone-down: *M* = 2.94 sec, *SD* = 1.16).

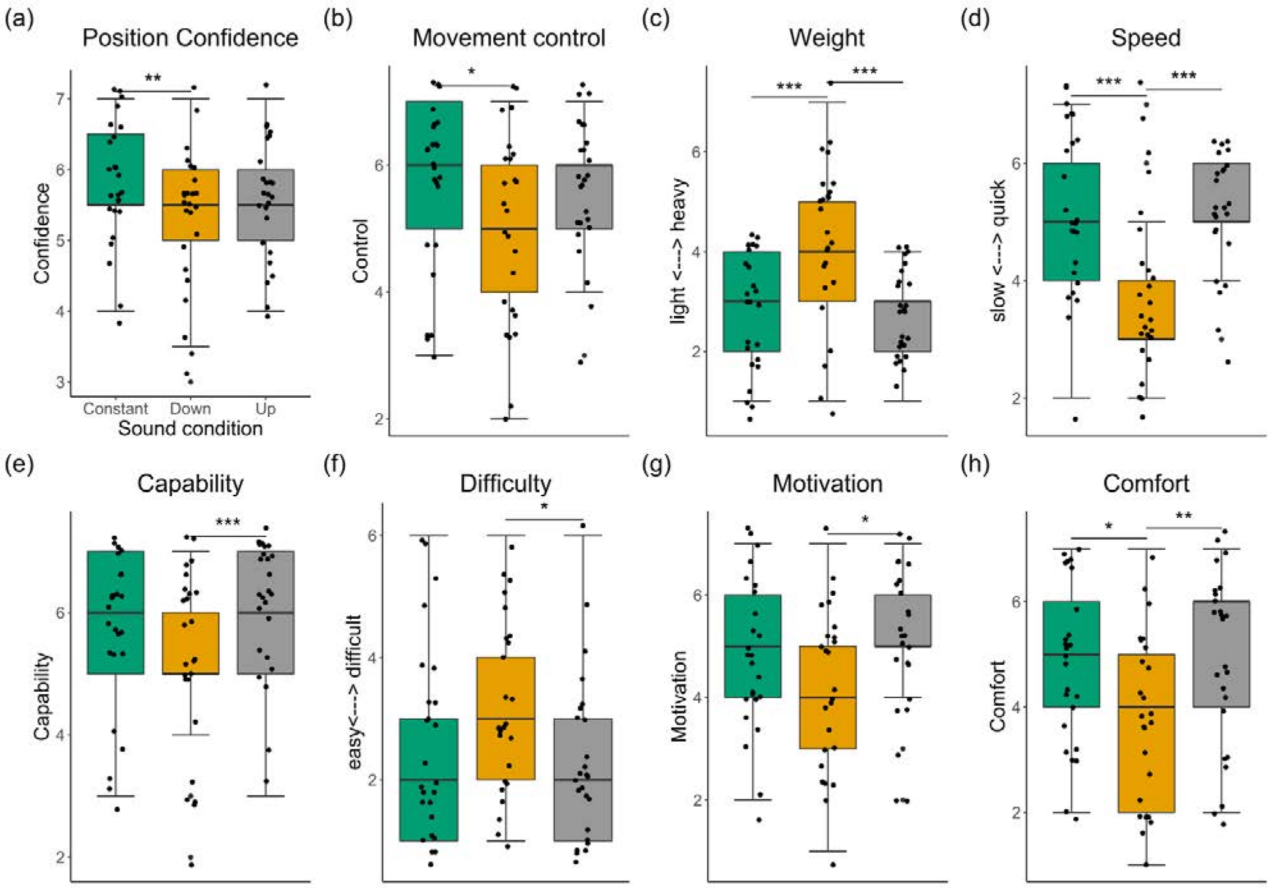


FIGURE 7.21: BOXPLOT WITH MEDIAN(RANGE) SCORE FOR THE FEELINGS OF CONFIDENCE IN HAVING REACHED THE REQUESTED POSITION AND FEELINGS ABOUT ONE'S BODY AND THE BODILY MOVEMENT FOR ALL SOUND CONDITIONS IN EXPERIMENT 1. (A) FEELINGS OF POSITION CONFIDENCE (COMBINING POSITION 1 Y 2); (B) FEELINGS OF CONTROL OVER MOVEMENT; (C) FEELINGS OF BODY WEIGHT AND (D) SPEED; (E) FELT CAPABILITY AND (F) DIFFICULTY TO PERFORM THE EXERCISE; (G) FELT MOTIVATION AND (H) COMFORT DURING THE EXERCISE. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < 0.05, ** INDICATES P < 0.01, *** INDICATES P < 0.001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

b) Effects on task confidence

Sound Direction had an effect on Task Confidence ($F(2,120) = 4.49, p = .037, \eta 2 = .128$), with no main effect of Position or interaction between factors. Participants were more certain about their hand position with the "Tone_constant" than with the "Tone_down" ($t(120) = 2.98, p = .01, d = .597$); no significant differences were found between the "Tone_up" and the other conditions (see FIGURE 7.21a). A significant correlation was found between the task confidence ratings and the actual performance (i.e., maximum angle) for the "Tone_down" and Position 1 ($r(25) = 0.53, p = .007$): participants were more certain about their arm being at Position 1 when the maximum angle was higher, even though their accuracy was not improved.

c) Effects on bodily and emotional feelings

Sound Direction had an effect on the sense of Control ($F(2,48) = 3.54, p = .037, \eta2 = .129$), with participants reporting having a larger sense of Control over their movement with “Tone_constant” than with “Tone_down” ($t(48) = 2.47, p = .045, d = .698$), see FIGURE 7.21b. There were no significant differences in Agency over the heard sounds across conditions ($p > .97$): for all conditions participants overall agreed that the sounds they heard were produced by them.

Sound Direction also had an effect on the sense of Lightness ($F(2,48) = 15.29, p < .001, \eta2 = .38$) and Speed ($F(2,48) = 10.50, p < .001, \eta2 = .30$). People felt lighter with the “Tone_up” ($t(48) = 4.87, p < .001, d = 1.378$) and “Tone_constant” ($t(48) = -4.70, p < .001, d = 1.33$) than with the “Tone_down” sound, as shown in FIGURE 7.21c. They also felt faster with the “Tone_up” ($t(48) = -3.91, p < .001, d = 1.108$) and “Tone_constant” ($t(48) = 4.02, p < .001, d = 1.136$) than with the “Tone_down” sound (FIGURE 7.21d).

Further, participants felt more capable of completing the exercise ($F(2,48) = 7.41, p = .001, \eta2 = .23$) with the “Tone_up” than with the “Tone_down” sound ($t(48) = 3.85, p < .001, d = 1.089$), (FIGURE 7.21e). They reported that the exercise was easier ($F(2,48) = 3.83, p = .029, \eta2 = .13$), with the “Tone_up” than with the “Tone_down” sound ($t(48) = 13.54, p = .025, d = .764$), FIGURE 7.21f, and feeling more motivated to perform the exercise ($F(2,48) = 4.62, p = .015, \eta2 = .16$), with the “Tone_up” than with the “Tone_down” sound ($t(48) = 3.03, p = .011, d = .858$), FIGURE 7.21g). Lastly, participants felt more in comfort ($F(2,48) = 6.25, p = .004, \eta2 = .21$) while performing the exercise with “Tone_up” than “Tone_down” ($t(48) = 3.37, p = .004, d = .953$) and with “Tone_constant” than “Tone_down”($t(48) = 2.61, p = .032, d = .739$) ; FIGURE 7.21h.

7.3.5.2. Experiment 2. Effects of harmonic content (Sound Direction and Timbre)

a) Effects on bodily movement

The analyses of the movement data showed a significant effect of the factor Position for all parameters. As expected, for the condition where participants were asked to reach Position 2, participants reached a higher “peak angle” ($F(1,24) = 417.69, p < .001, \eta2 = .79$) and showed also a higher “mean angle” ($F(1,24) = 346.56, p < .001, \eta2 = .54$). This effect of Position was reflected also in longer “time up” ($F(1,24) = 25.32, p < .001, \eta2 = .05$) and “time down”

$(F(1,24) = 44.61, p < .001, \eta 2 = .03)$, higher "velocity up" $(F(1,24) = 165.10, p < .001, \eta 2 = .36)$ and "velocity down" $(F(1,24) = 48.52.47, p < .001, \eta 2 = .23)$, and higher "acceleration up" $(F(1,24) = 187.47, p < .001, \eta 2 = .17)$, for Position 2 as compared to Position 1.

Apart from this main effect of Position, additional effects related to sound condition for the parameters "peak angle", "acceleration up" and "velocity up" were found. In particular, for "peak angle" was found a significant interaction between Sound Direction and Position $(F(1,24) = 5.76, p = .024, \eta 2 = .19)$, but post-hoc paired comparisons between Ascending and Descending sounds in the Position 1 $(p > .757)$ and in the Position 2 $(p > .976)$ were both not significant. For "acceleration up" a significant interaction between Sound Direction and Position $(F(1,24) = 6.25, p = .019, \eta 2 = .21)$ was found, a non-significant, but substantial, interaction between Sound Direction and Timbre $(F(1,24) = 3.87, p = .060, \eta 2 = .14)$ and a significant triple interaction between all factors $(F(1,24) = 6.19, p = .020, \eta 2 = .20)$. The interactions were follow-up by conducting separate ANOVAs for Position 1 and 2 with factors Sound Direction and Timbre. The ANOVA for Position 1 showed an effect of Sound Direction in upward acceleration $(F(1,24) = 6.44, p = .020, \eta 2 = .21)$, with higher acceleration for the Ascending (Normalized acceleration: $M = .127, SD = .049$) than for the Descending sound $(M = .121, SD = .048)$, and no significant effect of Timbre or interaction between factors $(p = .60)$. For Position 2, there was only a significant interaction between Sound Direction and Timbre $(F(1,24) = 8.08, p = .009, \eta 2 = .25)$; but the follow-up paired t-test comparisons were all non-significant.

For "velocity up" were found a main effect of Timbre $(F(1,24) = 6.30, p = .019, \eta 2 = .001)$, as participants were faster raising the arm when listening to the "Tone" sounds ($M = 36.13, SD = 12.07$ degrees/sec) than the "Musical" sounds ($M = 35.51, SD = 12.11$ degrees/s). Moreover, for "velocity up" there was a triple interaction of the factors Sound Direction, Timbre, and Position $(F(1,24) = 5.96, p = .022, \eta 2 = .20)$. Follow-up separate ANOVAs for Position 1 and 2 with factors Sound Direction and Timbre showed that for Position 1 there was a significant effect of Timbre $(F(1,24) = 5.89, p = .023, \eta 2 = .20)$ and an interaction between Sound Direction and Timbre $(F(1,24) = 4.61, p = .041, \eta 2 = .16)$; paired t-test comparisons were all non-significant. For Position 2 there were no significant effects or interactions $(F(1,24) = 0.58, p = .45, \eta 2 = .02)$.

b) Effects on task confidence

Task Confidence was significantly affected by the factors Sound Direction ($F(1{,}71) = 4.83, p = .031, \eta 2 = .063$), Timbre ($F(1{,}71) = 10.51, p = .001, \eta 2 = .12$), and Position ($F(1{,}97) = 7.96, p = .005, \eta 2 = .075$), with no significant interaction between factors, Sound Direction and Timbre ($p > .577$), Timbre and Position ($p > 0.203$). Sound Direction and Position ($p > .405$). As shown in FIGURE 7.21a participants were more certain about their hand position with the Ascending than with the Descending sounds, with the "Musical" than with the "Tone" sounds, and in Position 2 than in Position 1.

A significant correlation was found between the task confidence ratings and the actual performance (i.e., maximum angle) for the "Tone_up" ($r(25) = .40, p = .047$), "Musical_up" ($r(25) = .49, p = .013$) and "Musical_down" ($r(25) = .44, p = .028$) conditions. Follow-up separate correlation analyses for Position 1 and 2 revealed significant correlations only for the "Musical_up" sound, both in Position 1 ($r(25) = .45, p = .024$) and Position 2 ($r(25) = .50, p = .01$). As in Experiment 1, for all conditions participants were more certain about their arm being at the requested position when the maximum angle was higher, even though their accuracy was not improved.

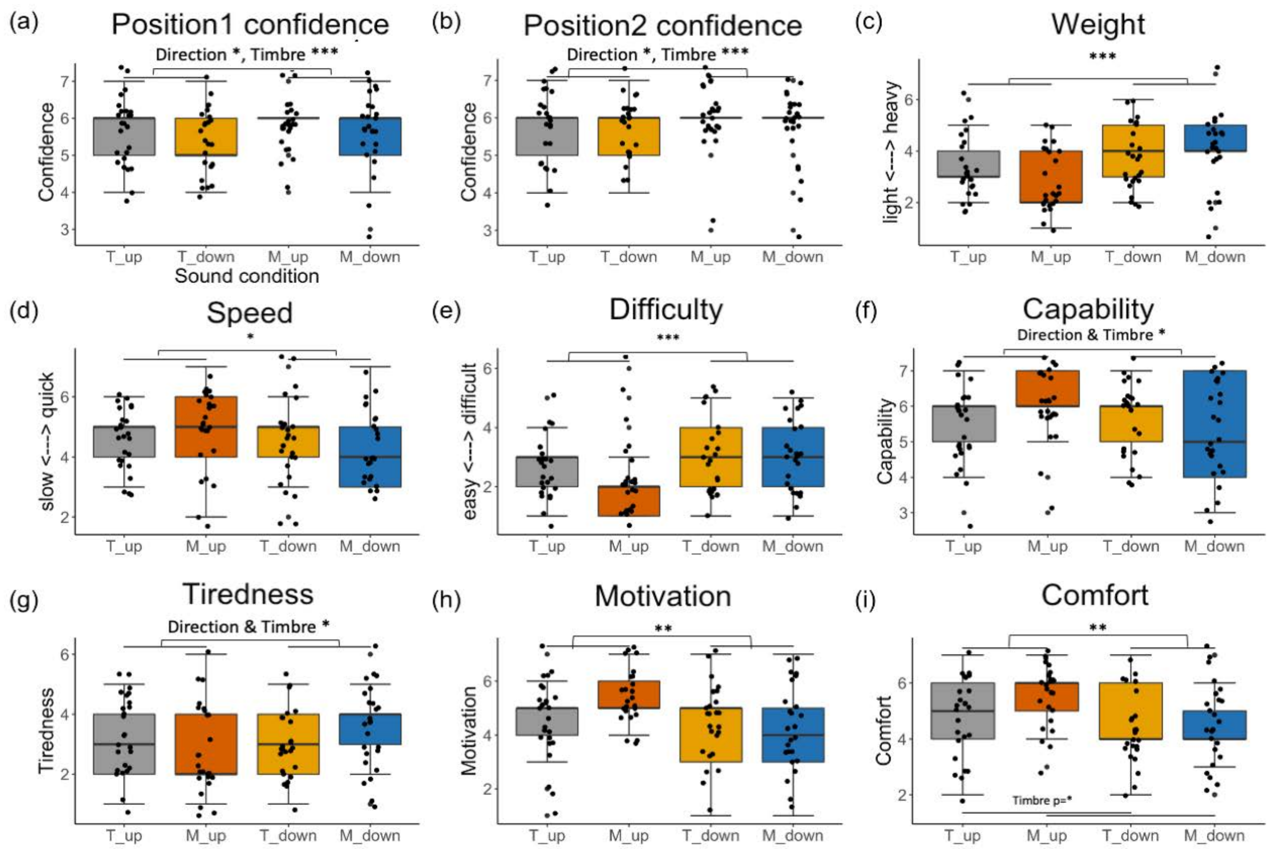


FIGURE 7.22: BOXPLOT WITH MEDIAN (RANGE) SCORE FOR THE FEELINGS OF CONFIDENCE IN HAVING REACHED THE REQUESTED POSITION, FEELINGS ABOUT ONE'S BODY AND THE BODILY MOVEMENT FOR ALL SOUND CONDITIONS IN EXPERIMENT 2. (A) FEELINGS OF POSITION CONFIDENCE IN POSITION 1 AND (B) POSITION 2; (C) FEELINGS OF BODY WEIGHT AND (D) SPEED; (E) FEELINGS OF DIFFICULTY, (F) CAPABILITY, (G) TIREDNESS, (H) MOTIVATION AND (I) COMFORT DURING THE EXERCISE. T_UP = "TONE_UP", T_DOWN = "TONE_DOWN", M_UP = "MUSICAL_UP", M_DOWN = "MUSICAL_DOWN". NOTE THAT IN FIGURES (A) AND (B), RELATED TO POSITION CONFIDENCE, FOR THE CONDITIONS MUSICAL_UP IN BOTH POSITIONS AND MUSICAL_DOWN IN POSITION 2 WE OBSERVE A LARGE CONCENTRATION OF PARTICIPANTS' ANSWERS AROUND POINT 6 OF THE SCALE, SUGGESTING THAT PARTICIPANTS FELT QUITE CONFIDENT ABOUT THEIR POSITION WITH ONLY FEW PARTICIPANTS DEVIATING FROM POINT 6. FOR THE OTHER CONDITIONS, WE OBSERVE LEFT- OR RIGHT-SKEWED DATA, DUE TO A LARGER DISPERSION IN PARTICIPANTS' RESPONSES. THE ASTERISKS INDICATE SIGNIFICANT DIFFERENCES BETWEEN SOUND CONDITIONS (* INDICATES P < .050, ** INDICATES P < .010, *** INDICATES P < .001; ALL CORRECTED FOR MULTIPLE COMPARISONS).

c) Effects on bodily and emotional feelings

In terms of Control over their movement ($p > .245$) and Agency ($p > .194$) over the heard sounds, there were no significant differences between conditions. Participants agreed that they felt in control of their movements and that the sound was produced by them in all conditions.

Sound Direction had a significant effect in feelings of Lightness, Speed, Difficulty, Motivation and Comfort: as shown in FIGURE 7.22, participants felt lighter ($F(1,71) = 12.69, p < .001, \eta 2 =$

$.15)$), faster $(F(1{,}71) = 5.39, p = .023, \eta 2 = .070)$), and reported that the exercise was easier $(F(1{,}71) = 13, p < .001, \eta 2 = .15)$, that they were more motivated to complete it $(F(1{,}71) = 9.21, p = .003. \eta 2 = .11)$ and felt more in comfort $(F(1{,}71) = 9.89, p = .002, \eta 2 = .12)$ with the Ascending sounds (Up conditions) as compared to the descending sounds (Down conditions).

Moreover, Sound Timbre showed a main effect for feelings of Comfort $(F(1, 71) = 4.65, p = .034, \eta 2 = .06)$, with participants reporting a higher feeling of comfort in the "Musical" sounds than in "Tone" sounds, as it can be seen in FIGURE 7.22.

Finally, though not significant, an interaction effect between the factors Sound Direction and Timbre were observed for the feelings of Lightness $(F(1{,}71) = 3.57, p = .062, \eta 2 = .04)$ and exercise Difficulty $(F(1{,}71) = 3.59, p = .061, \eta 2 = .048)$. This interaction reached significance for the feelings of Capability $(F(1{,}71) = 4.93, p = .029, \eta 2 = .06)$, Tiredness $(F(1{,}71) = 5.49, p = .021, \eta 2 = .071)$, Motivation $F(1{,}71) = 5.99, p = .016, \eta 2 = .077)$ and Comfort $(F(1{,}71) = 3.87, p = .052, \eta 2 = .051)$. The interactions were driven by the fact that the difference between Ascending and Descending sounds was larger for the Musical than for the Tone sounds: to a larger extent in the case of the Musical sounds, with ascending vs descending sounds participants felt lighter $(X^2(1) = 3.66, p = .056)$, more capable $(X^2(1) = 5.18, p = .023)$, less tired $(X^2(1) = 5.54, p = .018)$, more motivated $(X^2(1) = 6.10, p = .014)$, more comfortable $(X^2(1) = 4.05, p = .044)$, and found the exercise easier $(X^2(1) = 3.81, p = .05)$ (FIGURE 7.22).

7.3.5.3. Experiment 3. Effects of absolute frequency range (Sound Direction and Frequency Range)

a) Effects on behavior (bodily movement)

The analyses of the movement data showed a significant effect of the factor Sound Frequency Range on Peak Angle $(F(1{,}19) = 5.71, p < .027, \eta 2 = .23)$. The results showed that a higher peak angle was reached with "High Pitch" ($M = 101.32, SD = 13.70$ degrees) than with "Low Pitch" sounds ($M = 100.06, SD = 11.89$) degrees. Since the requested position was 90 degrees, participants were more accurate in their reached position for the "Low Pitch" sounds.

b) Effects on bodily feelings

Sound Direction had a significant effect on feelings of body Weight, Comfort and Coordination: participants felt lighter $(F(1{,}54) = 4.42, p = .040, \eta 2 = .075)$, more comfortable $(F(1{,}54) =$

$6.42, p < .014, \eta 2 = .106)$ and with more coordinated movements $(F(1,54) = 4.35, p = .041, \eta 2 = .074)$, with the "Musical_up" than with the "Musical_down" sounds (FIGURE 7.23). Furthermore, a substantial, although not significant, effect, of Sound Direction on Speed were observed $(p = .060)$, as participants felt considerably faster with the "Musical_up" than with the "Musical_down" sounds.

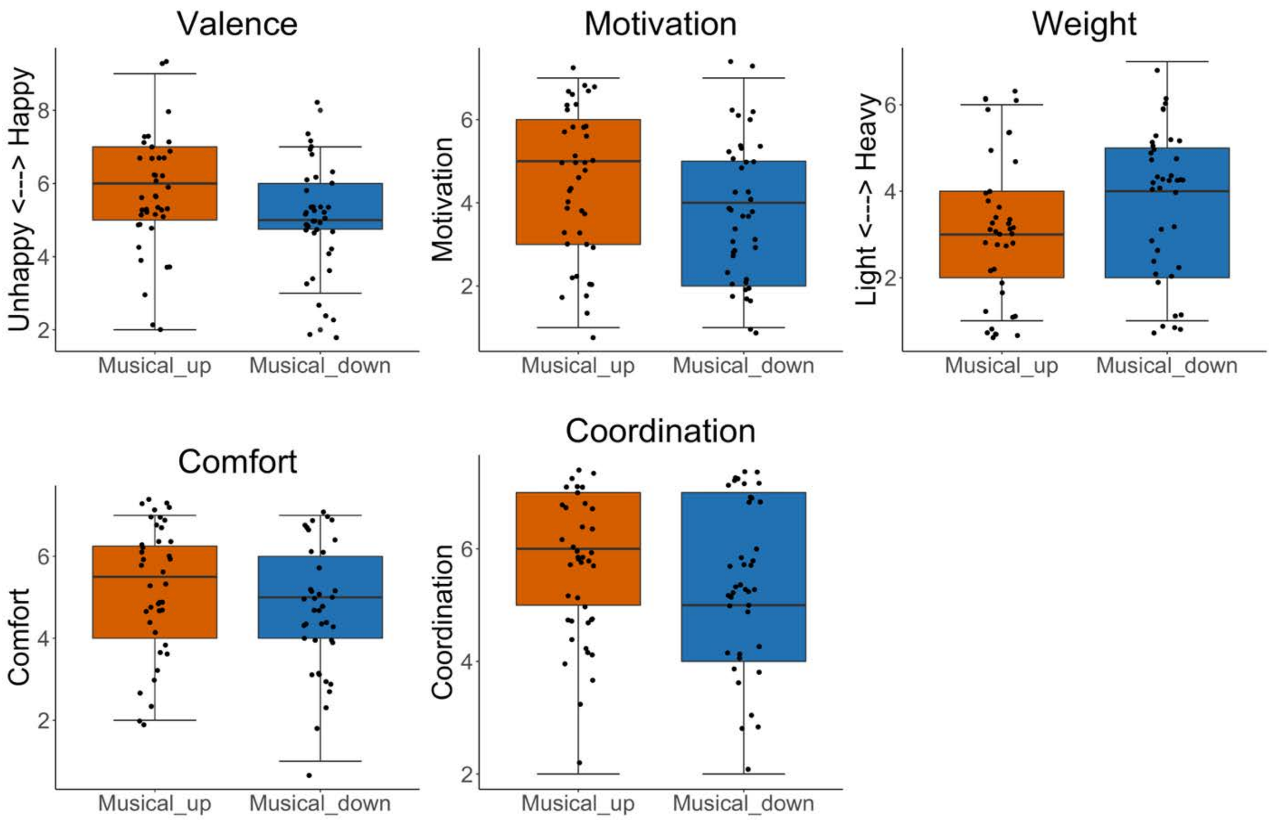


FIGURE 7.23: BOXPLOTS WITH MEDIAN(RANGE) SCORE FOR QUESTIONNAIRE ITEMS SHOWING SIGNIFICANT EFFECTS OF SOUND DIRECTION IN EXPERIMENT 3. (A) REPORTED EMOTIONAL VALENCE (HAPPINESS) AND (B) MOTIVATION; AND (C) FEELINGS OF BODY WEIGHT, (D) MOVEMENT COMFORT AND (E) COORDINATION.

With regards to Sound Frequency Range, there were effects on feelings of body Weight, Speed, Tiredness and Difficulty. "High pitch" caused participants to feel lighter $(F(1,54) = 21.07, p = .001, \eta 2 = .281)$ and faster $(F(1,54) = 28.31, p = .001, \eta 2 = .34)$ than "Low_pitch" sounds. Further, the "Low_pitch" made participants feel more tired $(F(1,54) = 13.10, p = .001, \eta 2 = .195)$ and with more difficulty $(F(1,54) = 6.37, p = .014, \eta 2 = .105)$ to perform the exercise than the "High_pitch" sound, see FIGURE 7.24.

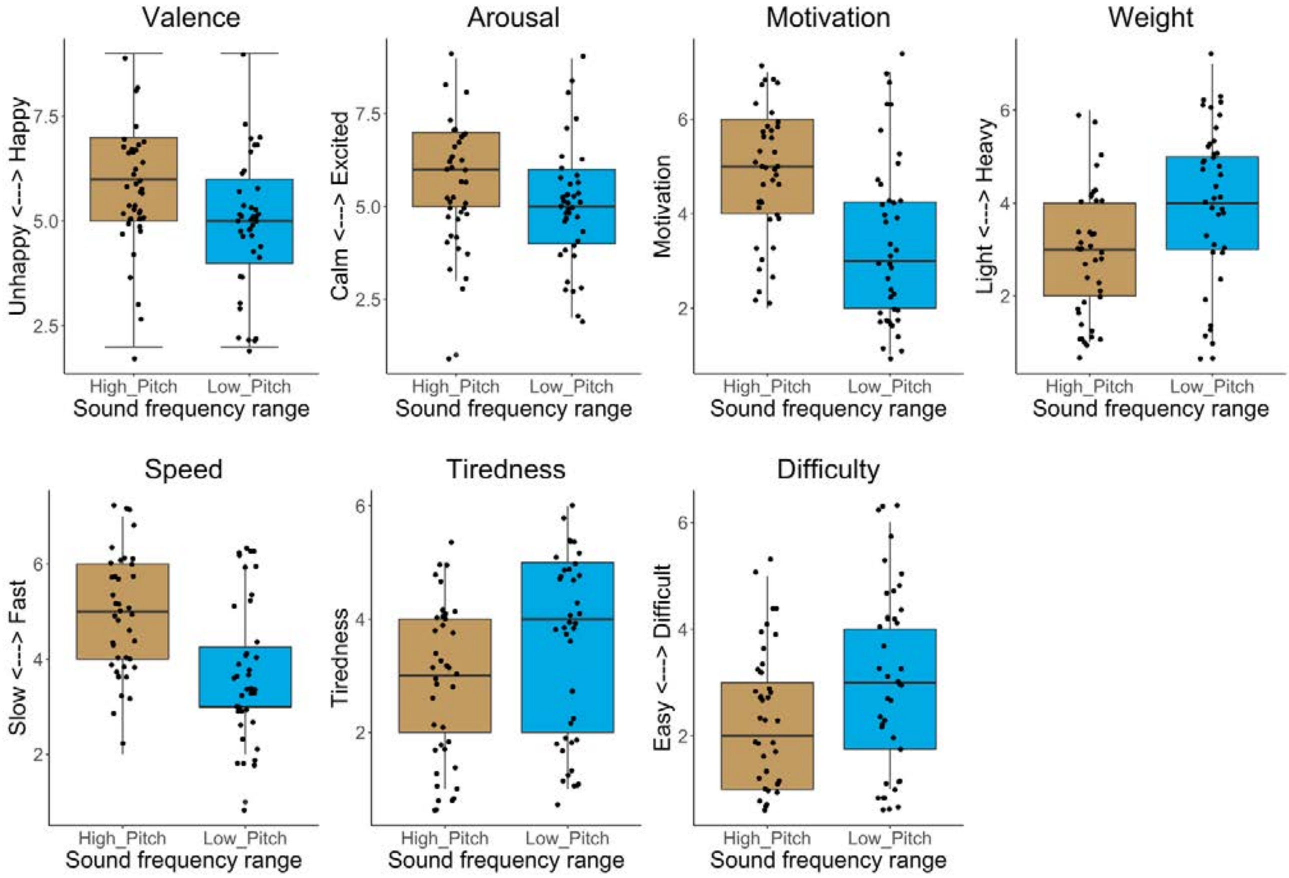


FIGURE 7.24: BOXPLOTS WITH MEDIAN(RANGE) SCORE FOR QUESTIONNAIRE ITEMS SHOWING SIGNIFICANT EFFECTS OF SOUND FREQUENCY RANGE IN EXPERIMENT 3. (A) EMOTIONAL VALENCE (HAPPINESS), (B) AROUSAL (EXCITATION), AND (C) MOTIVATION; (D) FEELINGS OF BODY WEIGHT, (E) SPEED, AND (F) TIREDNESS; AND (G) MOVEMENT DIFFICULTY.

There was a significant interaction between Sound Frequency Range and Direction in relation to feelings of Tiredness ($F(1,54) = 7.05, p = .010, \eta 2 = .115$). Follow-up tests showed that the "Musical_down_Low_pitch" sound caused participants to feel significantly more tired than the other sound conditions ($X^2(1) = 5.54, p = .018$). There was also a substantial, though not significant, interaction effect between Sound Direction and Sound Frequency Range for Coordination ($F(1,54) = 3.84, p = .066, \eta 2 = .061$), which was mainly due to the "Musical_down_Low_pitch" sound causing participants to feel less coordinated than the other sound conditions.

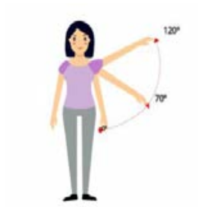
Finally, in terms of Strength ($p > .219$), Capability ($p > .943$), movement Control ($p > .376$), and Agency ($p > .086$) over the heard sounds, there were no significant effects. For all conditions participants agreed that they felt in control and capable of their movements.

c) Effects on emotional feelings

Sound Direction had a significant effect on reported emotional Valence and Motivation. Participants felt happier ($F(1,54) = 5.60, p < .021, \eta 2 = .093$) and more motivated ($F(1,54) = 5.40, p = .020, \eta 2 = .095$) with the "Musical_up" than with the "Musical_down" sounds, independently of the Sound Frequency Range (see FIGURE 7.23). The effect of Sound Direction on reported Arousal was not significant ($p = .077$), although results showed that participants felt considerably more excited with the "Musical_up" than with the "Musical_down" sounds.

With regards to Sound Frequency Range, there was a significant effect on emotional Valence and Motivation, and a considerable, though non-significant effect, on Arousal. "High pitch" caused participants to feel happier (valence; $F(1,54) = 4.14, p = .047, \eta 2 = .071$), more motivated ($F(1,54) = 19.55, p < .001, \eta 2 = .265$), and more excited (arousal; $F(1,54) = 3.12, p = .082, \eta 2 = .054$) than "Low_pitch" sounds (FIGURE 7.24).

TABLE 7.12 SCHEMATIC SUMMARY OF RESULTS ON THE EFFECTS ACROSS ALL THE EXPERIMENTS

Dimension		Predicted effects	Effects of Pitch change	Effects of Timbre (vs Tone)	Effects of absolute frequency range
Bodily movement 		Amplitude	✗	✗	✓
		Acceleration/ velocity	✓	✓	✗
Proprioceptive awareness 		Accuracy of final position	✗	✗	✓
		Confidence on perceived final position	✓	✓	not assessed
Bodily and emotional feelings 	Feelings about the body	Weight	✓	✓	✓
		Speed	✓	✗	✓
		Tiredness	✓	✓	✓
		Strength	✗	not assessed	✗
	Feelings about the movement	Sense of control	✓	✗	✗
		Ease	✓	✓	✓
		Comfort	✓	✓	✗
		Capability	✓	✓	✗
		Coordination	✓	not assessed	✗
	Emotional feelings	Motivation	✓	✓	✓
		Happiness	✓	not assessed	✓
		Arousal	✗	not assessed	✗

7.3.6. Conclusion[12]

This study investigated how body-representation and feelings would be influenced by various sound characteristics when performing a basic movement that is accompanied by a sound. I looked more specifically at how bodily movement, proprioceptive awareness (sustained by body schema) and subjective feelings related to the body, one's movement, and emotional state, are affected by auditory changes. Three experiments studied the effects of pitch direction in tones (Experiment 1), richer musical features (Experiment 2), and absolute frequency range (Experiment 3). Overall, as shown in the summary TABLE 7.12, changes in pitch had effects on the emotional state and on the various bodily dimensions investigated bodily movement, proprioceptive awareness, bodily feelings with more comprehensive effects observed for the latter explicit measures. Richer sound timbre and accentuated attack affected the confidence of participants about their body position, as well as the velocity of their movement, but mostly amplified the measured differences between ascending and descending pitch sounds in bodily feelings. Shifting the absolute frequencies of the descending pitch sounds impacted the amplitude of the performed movement (and therefore the accuracy of the final reached position according to the experiment task), and interacted with participants' feelings of tiredness. It also had a general effect on feelings of happiness and other bodily feelings[13].

a) Pitch change and bodily movement

The previous evidence (see TABLE 7.9) allowed to hypothesized that pairing movement with pitch changes, generally not associated with body movement, could be sufficient to lead to proprioceptive changes, as well as changes in movement and feelings, due to cross-modal correspondences between pitch change and motion on the vertical axis [173]–[175]. As suggested by previous works [16] "the changes in perceived sound localization induced by sounds changing in pitch [197] interact with internal models of body-representation" was hypothesized. The hypotheses are partly confirmed by these results. As shown in TABLE 7.12, the self-reports (with partial behavioral support) did reveal

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[12]This conclusion (Section 7.3.6) has been written in collaboration with senior researchers and in turn co-authors where the study was published.

[13]To obtain more details of the conclusion it is recommended to read the article, https://doi.org/10.1038/s41598-022-06210-x

that the multisensory interaction between pitch and bodily movement can impact bodily experiences, and point towards a potential interference of sound with proprioception.

Results found that a sound increasing or decreasing in pitch triggered at the beginning of the participant's arm movement led participants to become less confident about their arm position than with a constant sound. Further, Results found that, for the conditions with sounds changing in pitch, increases in participants confidence were not accompanied by increases in actual performance (i.e., more accurate position reached) but rather by overall increases in the reached angle, thus suggesting a degradation in the ability to judge accurately the arm position [16], [63].

Other studies with vision showed that altering the perceived feedback on the position of a moving limb results in adjustment in the participant's limb movement [196]. This study shows similar effects of changing pitch on bodily movement. The arm movement amplitude was not strongly affected, but in Experiment 2 the movement acceleration triggered by the ascending pitch sound was. This allow to hypothesize that this increase in acceleration probably reflects a compensatory response mediated by auditory feedback signaling a discrepancy between the predicted position and the received sensory feedback. Such corrections in velocity/acceleration have been observed in other studies providing altered sound feedback, for instance, on the trajectory of a movement [198] or on the applied weight on the floor when walking [199].

Further, the results found that sounds changing in pitch affect participants' feelings about their body and their movement. With the "Ascending" sound participants feel, for instance, lighter and quicker, and find the upwards movement easier to perform, than with the descending sound. This feeling is attributed to the perception of being "pushed up" by the "Ascending" sound, which is compatible with the facilitation of the upwards movement. Lastly, this study found an effect on emotional state, in line with the affective correspondence between raising pitch and happiness [162], [164].

Future research should investigate whether these effects of the ascending vs. descending sound reverse or hold for a downwards movement, as previous studies on the "auditory Pinocchio" illusion showed that the effect does not reverse when inverting the direction of finger pulling [16].

b) Harmonic content and bodily movement

Experiment 2 shows that musical sounds, as compared to the tone sounds, made people feel more confident of having reached the requested position, increased the feeling of comfort in performing the movement, and decreased the velocity of the upwards movement. While confidence increased with harmonic complexity, such increases in confidence were not accompanied by increases in actual performance.

As these effects occurred both for ascending and descending sounds, they may relate to the emotional processes triggered by the musical sounds, as these sounds are generally more pleasant to listen to than pure tones (see [200] for low frequency). Musical sounds are also ecologically more valid: they are closer to sounds that the participants are familiar with, while the tone sounds are typically found only in specific electronic devices. They also provide more possibilities in terms of designing sonification that may impact body movement. Previous studies have shown that the mapping of musical features (e.g., tempo, pitch, etc.) to movement properties (e.g., movement velocity, body inclination) can be used to improve the understanding of full-body movement and expressive gestures and to drive movement behavior [201], [202]. For instance, Newbold et al. showed that musical structures could be embedded into the sonification of movement to manipulate the feeling of wanting to continue or conclude a movement and the feeling of accomplishment [25], [176]. Note that differently from those studies, here sounds that do not provide accurate spatial information about the movement were used: once the sound is triggered this sound does not change according to movement (i.e., the movement is not sonified) and the sound is irrelevant to the movement task. The participants highly likely never experienced such coupling of their movement with sound; thus, it can be assumed they did not have any clear expectancy on the movement-sound coupling.

Beyond this general effect, results also showed that the musical features interacted with the overall effect of changes in pitch in several bodily feelings. The musical effect was not that of purely enhancing the bodily effects in the positive direction, but on increasing the difference between ascending and descending pitch sounds for the musical versus the pure tone sounds. People felt even lighter and more comfortable with the ascending vs. the descending musical sound, than they did for the pure tones. People felt less tired with the ascending musical sound and more tired with the descending musical sound, than they did for the pure tones. Feelings of capability and motivation to perform the movement were lower for the descending musical sound than for the other sounds, while the movement seemed easier with the ascending musical sound than for the other sounds.

c) Absolute frequency range and bodily movement

In Experiment 3, results found that shifting the absolute frequencies of the changing pitch sound impacted the movement, as well as the emotional state, and bodily feelings, of the participants. In particular, the higher frequency sound increased the amplitude of the participants' arm raise movement, making the arm reach a higher peak angle. People felt happier, lighter, less tired, more motivated and found the movement easier with the higher frequency sound as compared to the lower frequency sound. Because these effects were independent of the movement direction, they probably relate to two different processes. On the one hand, apart from vertical space, pitch is associated with physical size must be considered. High and low pitches are respectively congruent with smaller and larger sizes, as shown for the perception of object size [180]–[184] and for the perception of people's body size [203], [204]. Shifting the pitch of one's own bodily produced sounds (i.e., footstep sounds) has been shown to change how people perceive their own body size and weight [17] and also to make people find exercises less difficult and feel less tired [33]. Similarly, in this current study the feelings of being lighter, less tired, more motivated and finding the exercise easier, which were elicited by the high pitch sounds, may have pushed participants to raise their arms higher. Second, the emotional processes triggered by the high frequency sounds, which made participants feel happier, as shown by the results, may have interacted with the bodily feelings, or both processes may have influenced each other. The findings here relate to those from a previous qualitative study where bodily movement was paired with a sound rising in pitch similar to the musical sound employed in Experiment 3; this study suggested that this sound could lead to more pleasantness and feelings of movement fluidity, body lightness and flexibility in the context of exertion, as it was observed in the previous study of this chapter.

Beyond this general effect of pitch, results showed that the absolute frequency range interacted with the effect of the change in pitch (i.e., the relative pitch) in the feelings of tiredness. The interaction effect showed that the difference between ascending and descending pitch sounds was amplified for the low pitch versus the high pitch sounds. With the low pitch sounds people felt less tired with the ascending sound than with the descending sound, but with the high pitch the change in pitch did not seem to have an effect and people felt overall less tired than with the low pitch sounds. Several studies also show that the association of pitch variation and frequency ranges with movement does not follow simple rules and can be highly influenced by the context [205]. In [175], by asking participants to describe sounds gesturally, they confirm that pitch variations are typically associated with spatial metaphors. Finally, it should be noted that different asymmetries have been found whether sound parameters increase or decrease, even if absolute changes are identical. Pitch perception and its association to movement can depend on the direction [206]. Sounds with increasing intensity sounds are perceived as being longer and their range of loudness appears to be higher [207]. More investigations are necessary to disentangle the different possible cross-modal associations of sound features, also in relation with people skills and background [208].

Finally, to better study the congruence between pitch and motion direction, future work could focus on investigating the effect of ascending and descending pitch sounds accompanying both upwards and downwards movement. While in the present study the movement chosen (arm raise) demands effort only on the upwards part of the movement, a movement or exercise similarly demanding on both upwards and downwards movement may be better chosen for such investigations. Furthermore, future research may consider comparing the effects of the sounds changing in pitch to a "no sound" condition; note that in the present study the constant sound was included in Experiment 1 as a "control" or reference condition with which to compare the effect of the sounds changing in pitch (as in [16], [63]), as opposed to a "no sound" condition, in order to control for the effect of simply listening to a sound.

8. QUALITATIVE STUDIES

The previous chapter focused on quantifying the sound effects in the exercise performed, as measured by sensors, as well as the effects in a limited set of predetermined body feelings measured by a questionnaire. Yet, a better understanding and surfacing of how the metaphorical sound characteristics help to produce the effects is missing, which limits our understanding of how to build such sonifications in relation to people's perceptions of themselves and of their capabilities. This chapter proposes to investigate how metaphorical sounds, and in particular their characteristics, lead to changes in BP, impact movement, and facilitate PA. This chapter will also be studying how effects hold over time, with more exposures, and how the effects differ between active and inactive populations and context of use (**RQ4**: "*How can interactive sonification be used in the long-term and in everyday environments (i.e., in the wild) to promote physical activity in physically inactive adults?"*). Following the findings of the quantitative studies, this chapter present two qualitative studies with different populations that engaged in exercising with the Sonification Band (SoniBand) and various sound conditions. The first study focuses on strength exercises and the second study on warm-up, strength, and flexibility exercises. These two studies are presented in detail in their corresponding sections, focusing on the participants, the sounds employed, the exercises featured, procedural aspects of the study, and data gathering methods. TABLE 8.1 provides an overview summary that compares both studies.

TABLE 8.1: SUMMARY TABLE COMPARING THE TWO STUDIES, STUDY 1 ACTIVE PEOPLE (AP) AND STUDY 2 INACTIVE PEOPLE (IP), IN TERMS OF PARTICIPANTS, SOUNDS EXPLORED, TYPES OF MOVEMENTS PERFORMED, NUMBER OF REPETITIONS, AND METHODS OF DATA COLLECTION.

	Participants	**Sound**	**Exercise selection**	**Nª of repetitions**	**Methods**
Study 1 (AP)	7 physically active people (AP)	Water, Wind, Mechanical, and Tone	Leg lifts, squats, and step-ups	>= 3 reps	Contextual body maps, semi-structured interview
Study 2 (IP)	5 physically inactive people (IP)	Water, Wind, Mechanical, and Beep	Warm-up (heel lifts, bend-and-stretch). Strength (lateral raises, leg lifts, knee lifts, squats, step-ups). Flexibility (thigh stretch, side arm raise)	3 type of exercises, between 2 and 3 sets per exercise (1 set =15 reps)	Diary, body maps, weekly semi-structured interviews

8.1. Author contributions and related publication

Two qualitative studies are presented in this chapter. In study 1, I contributed to the conception, and design of the work. In study 2, I was responsible for the recruitment, acquisition, and analysis of the data, as well as for the conception and design of the work with supervision from other senior researchers from the research team.

In both studies, I worked in the development of the sonification mappings, the software and hardware for movement sonification and data acquisition. I was responsible for the interpretation and writing of the studies together with another Ph.D. student and with supervision from other senior researchers from the research team[14].

Part of this study has been published in the form of a conference paper. The full reference of the paper is:

> *Ley-Flores, J.*, Turmo, L., Berthouze, V. N. B., Singh, A., Bevilacqua, F., & Tajadura-Jimenez, A. (2021). SoniBand: Understanding the effects of metaphorical movement sonifications on body perception and physical activity. Conference on Human Factors in Computing Systems - Proceedings. https://doi.org/10.1145/3411764.3445558

8.2. Study 1: Physically Active People Study.

Study 1 (also referred to as Active People (AP) study, TABLE 8.1) is mainly aimed to obtain a nuanced understanding of the effects of the sonifications' characteristics on the perception of movement qualities, and the impact they had on the immediate PA.

8.2.1. Methods

8.2.1.1. Participants and setting

The study involved 7 participants (age Range= 25 – 32; n=7, 3 females, 4 male) recruited at the University College London Interaction Centre, who participated in three 45' sessions, spread over a month. They were recruited through convenience sampling from the researcher's pool of contacts at University College London. As compensation for their participation, they were asked to participate

[14] As my Ph.D. thesis was developed in the framework of a bigger research project www.magicshoes.es the study was in collaboration with a Ph.D. Student from Uppsala University, Laia Turmo, and with researchers at University College London, where the data for Study 1 was collected.

in a raffle to win £25 (Appendix R). All 7 participants scored high levels of PA in the IPAQ (>1500 METS/week of vigorous activity alone; or >3000 METS/week any type of activity combined).

TABLE 8.2. PARTICIPANTS' INFORMATION FOR WORK STUDY.

ID	Age	Gender	PA level
P1-AP	25-34	Female	High
P2-AP	25-34	Male	High
P3-AP	25-34	Male	High
P4-AP	25-34	Female	Moderate -High
P5-AP	25-34	Female	High
P6-AP	25-34	Male	High
P7-AP	25-34	Male	High

Exercises

Our selection of exercises is based on guidelines to do more PA by the UK National Health Service (NHS) [140], which recommends a general warm-up and different programs of activity. The general warm-up, the strength, and flexibility exercises were the target as well as in quantitative studies and due to the little space that participants had performing the exercise in their rooms. Participants start with the general warm-up, and continue with the strength and the flexibility program, in this order but with the freedom to select by themselves one exercise of each program. For the general warm-up, heel lifts and bend-and-stretch exercises were chosen as they focus on building cardiorespiratory condition, coordination, and balance and prepare the body for subsequent exercises. From the strength program, upper body (lateral raises), lower body (leg lifts, knee lifts), and full-body (squats and step-ups) exercises were chosen. These exercises aim at developing coordination, balance, muscular strength, and cardiorespiratory endurance through repetition. From the flexibility program, "thigh stretch" and "side arm raise" exercises were chosen to increase the range of movement in the joints, proprioception, agility, and balance in the case of thigh stretch. Exercises used for each study are detailed in the dedicated study sections.

The AP study featured only exercises from the strength program (leg lifts and squats), as the other two exercise programs were deemed very basic and easy for an active population, which might lead to non-adherence or lower interest in the study due to a lack of challenge.

8.2.1.2. Apparatus and stimuli

a) SoniBand: mobile version

In order to investigate the effect of metaphorical sounds on BP and PA, SoniBand was developed, a wearable device based on [141], [187], but which was adapted to be more compact and ubiquitous. The device consists of a wearable band with integrated movement sensors and a smartphone, both connected to a Raspberry Pi Zero (a small board computer), and a specially developed web application implemented using Node.js to sonify the detected movement angle.

The wearable band (see FIGURE 8.1) is a self-locking band equipped with a hand-sewn cloth pocket containing a wireless emitter (BITalino R-IoT embedding a 9-axis Inertial Motion Unit (IMU) digitized at 16 bits). The band wirelessly transmits data using Wi-Fi, to the Raspberry Pi Zero, which generates the movement sonification in real-time and stores the data. The Raspberry Pi Zero can be controlled using a web browser, for example using a smartphone. This allows for setting-up various gesture-sound mappings (i.e., sonifications) through a graphical user interface, and for calibrating the device to the range of movement to be sonified for a specific person. This requires registering the configuration of the body part to be sonified at the start (minimum movement angle) and at the end of the movement (maximum movement angle).

FIGURE 8.1: (1) BAG WITH THE MATERIAL DELIVERED TO PARTICIPANTS (2) R-IOT WITH BATTERY, AND RASPBERRY PI ZERO WITH PORTABLE BATTERY; (3) USER INTERFACE OF THE WEB APPLICATION; (4) EXAMPLES OF HOW TO USE THE SONIFICATION BAND, WHEN IT WAS PLACED ON THE (5) USER INTERFACE OF CALIBRATION IN THE WEB APPLICATION (6) AN EXAMPLE OF CALIBRATION IN WHICH THE START EXERCISE POSITION (SET MINIMUM) AND END POSITION (SET MAXIMUM) ARE RECORDED AND STORED.

Wearability: Prior to the studies with the participants, it was explored the wearability of the prototype (SoniBand), trying different combinations of movement, sounds, and limbs to locate where it would work best to place the SoniBand during the exercises. That is, to capture the angular movement characterizing the specific exercises, and to know where it would be more comfortable to wear the SoniBand.

b) Sound stimuli

To explore the impact and effects of metaphorical sounds with a variety of meaning and sound characteristics, four different movement-sound conditions for SoniBand were designed: “Wind”, “Water”, “Mechanical”, and “Tone”, which are briefly described in TABLE 8.3 below. These sonifications were meant for repetitive physical exercises. “Wind”, “Water” and “Mechanical” sonifications were based on the quantitative studies and [141]. “Wind” aims to build on feelings of movement fluidity, effortless, speed, and agency, based on [112], [126]. “Water” aims to build on feelings of movement fluidity together with effortless weight [41] as well as to increase pleasant feelings and calm, based on [25], [209]. “Mechanical" aims to enhance control/proprioception, based on [41]. Also, it was decided to include a musical sound (called “Tone”), to test the potential effect of triggering a sound that “pulls the body”, drawing on the well-documented capacity of dynamic changes in pitch to elicit impressions of motion along with the vertical plan [16], [159]. As this study was performed previous to the Study 3 (Chapter 7) at this point the effects induced by listening to this sound were unknow. The hypothesis was this sound may encourage the continuation of the movement and enhance the sense of agility, speed, and capability to perform the movement.

TABLE 8.3: OVERVIEW OF THE CHARACTERISTICS OF EACH SOUND. THE TABLE OFFERS A GENERAL DESCRIPTION OF THE SOUND AND STATES HOW THE SOUND WAS DESIGNED TO ADDRESS PSYCHOLOGICAL BARRIERS TO PA RELATED TO SELF-BP’S WHICH HAVE BEEN REPORTED IN THE LITERATURE [6] BASED ON THE EFFECTS FOUND IN [1], [26], [27], [129], [210], [211].

Sound	**Description**	**Psychological barriers to PA addressed (based on previous findings)**
Water	It is a continuous sound of running water, which plays during the whole movement with a “splash” sound (with different timbre) at 10% after the start/end position.	-Perception of poor fitness status and dissatisfaction with perceived body appearance: e.g., low level of fitness [6]or not able to move faster [41] (“Water” affected sense of lightness, speed, agility, flexibility and body fluidity in ([187]); - Negative emotional state [6] (“Water" elicited feelings of playfulness and calmness in [187]).
Wind	It is a continuous filtered pink noise sound, imitating wind sounds, which plays uninterrupted throughout the whole movement, changing in frequency (from 600 to 1100 Hz peak frequency) in relation to angular movement.	-Perception of poor fitness status [6] (“Wind” affected sense of flexibility, speed and body fluidity in [187]); lack of sense of control and confidence in one’s body, lack of self-efficacy [6] (information on angular movement increased both in [41], [212]).
Mechanical	It is a discrete sound similar to rusty gears that plays throughout the movement with gradual changes in frequency (700 – 1100 Hz) and speed as it gets closer to the two calibrated start/end points of the movement.	-Lack of sense of progress and achievement; lack of sense of control and confidence in one’s body, lack of self-efficacy [6] (discrete information on angular changes was shown to enhance sense of achievement, self-efficacy and sense of control in [41]).
Tone	A sound akin to a spring (tonal sound with fast-incremental change in frequency, from note C5 to C6), that plays a short time (0.9s) at the start/end calibrated positions.	-Perception of poor fitness status (e.g., agility) [6] and sense of "feeling stuck" (i.e., not able to initiate movement) [68] (explore potential effect of triggering a sound that “pulls the body” [16]).
Beep	Flat tone with frequency of 440 Hz (sine wave) that plays only for a short time at the start/end calibrated positions.	None (used as a “control” or baseline sound).

Each of these sonifications presented potential effects from previous research [141], [187], with particular sound characteristics (e.g., timbre, frequency) and metaphorical qualities (e.g., “pulling the body” effect in Tone). Particular sound characteristics were chosen to ensure that the metaphorical quality would be perceived, and both were designed to address psychological barriers in the literature [6] related to negative or distorted self-BPs.

8.2.1.3. Measures

Body Maps:

Body Maps are used to facilitate ad-hoc reflection on bodily experiences. Body Maps usually consist of a body silhouette and a list of items (e.g., emotions, felt sensations), to encourage participants to link items that apply to their experience to the silhouette, e.g.: connect an item and a body part. The maps in both studies included 9 items of body properties based on [15], [60], with the option to add new properties.

- The first 5 items were related to BP:
  - strong – weak, **strength**
  - tense – relaxed, **stress**
  - flexible – stiff, **flexibility**
  - heavy – light, **lightness**
  - pleasing – unpleasing, **pleasantness**
- The other 4 items were related to body movement:
  - fluid – not fluid, **fluidity**
  - agile – not agile, **agility**
  - in control – not in control, **movement control**
  - slow – quick, **speed**
- Participants could also interpretatively draw on top of the silhouette, or highlight other perceptions, not on the list of items.

In the AP study, it was used a contextual Body Map (see FIGURE 8.2), which features a printed silhouette of the body performing a specific exercise, to further support and ground the participant's reflection on the impact of the sonification in the very movement they had performed. The silhouette shape is intended to enable participants to better ground particular perceptions and feelings to specific body parts or exercise phases. Body Map was used as a situated inquiry and probe tool, encouraging participants to fill it up and draw on it as they reflected aloud on their experience. The participants' drawings were used to ask oral questions and maintain a discussion with the participants about their experience on the exercise and the sonification Appendix T.

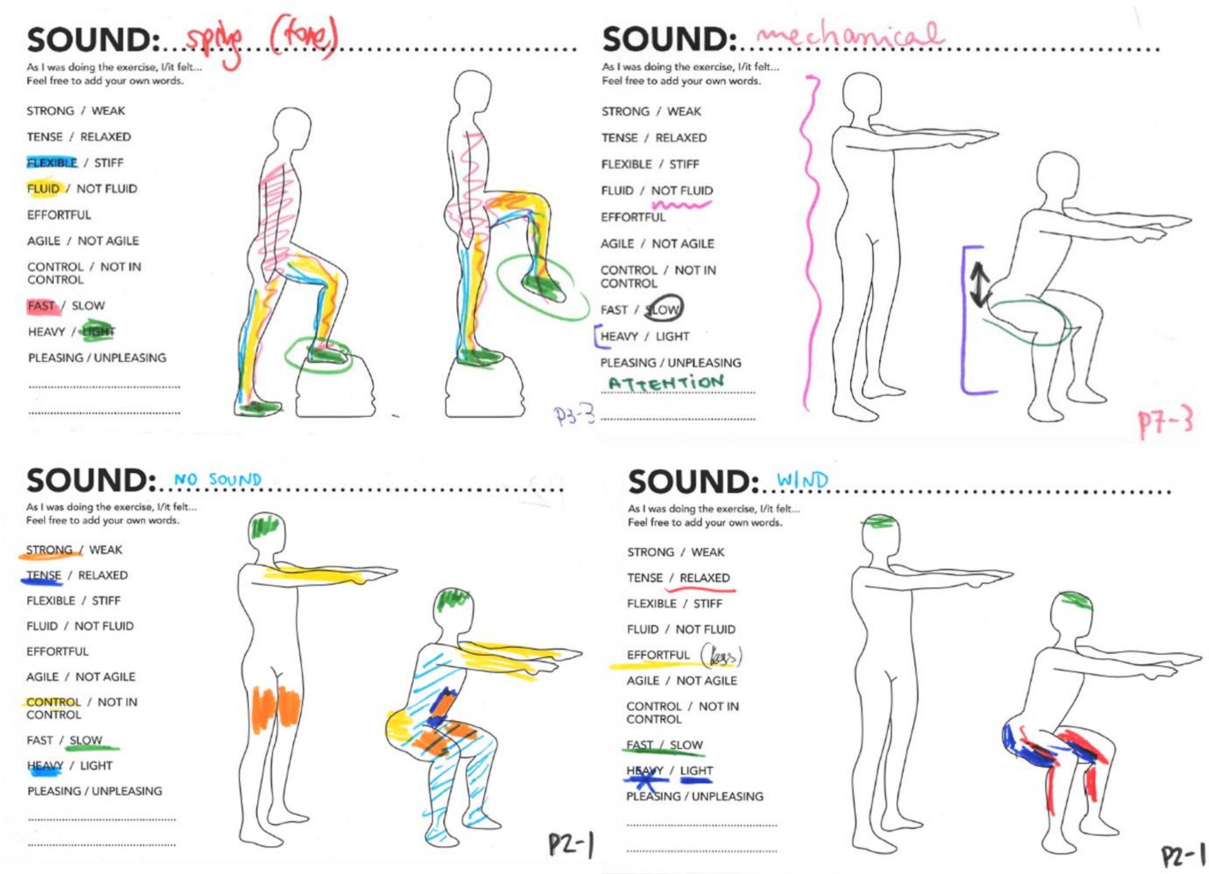

FIGURE 8.2: TWO FILLED CONTEXTUAL BODY MAPS, ONE DEPICTING HOW THE TONE SOUND HAS AFFECTED P3-AP'S BP'S DURING STEP-UPS; THE OTHER DEPICTING THE SAME FOR THE MECHANICAL SOUND DURING P7-AP'S SQUATS, LASTLY THE NO SONIFICAITON AND THE WIND WITH P2-AP.

8.2.1.4. Experimental procedure

Each participant engaged 3 times during their work hours, in a 45-minute session each time, with the researcher. Rather than randomizing the order of exposure to sound conditions, it was decided to add a new sound at each session and to remove one to keep the number of conditions limited as illustrated in TABLE 8.4. Sounds were added at each session according to their level of complexity, which is here defined as whether the sonification carries information about 1) the movement trajectory and 2) the movement range covered. For example, Wind was considered the less complex in structure as there were no changes in the sound characteristics other than the increase in frequency. Mechanical was similar to Wind, but was discrete and presented changes in frequency and speed. Water was instead considered more complex as it was formed by two different phases, the splash and the water stream. It also carries a more direct perceptible link (the splash) between the amount of movement performed. This incremental exposure to more informative sound was done to ensure that the analysis of the impact of a simpler sound would not be shadowed by the one created by more informative ones. Finally, the Tone sound condition was added to highlight the start and ending positions of an exercise and with extra information of impulse. Tone was used as tones have been extensively used in exercise sonification to provide points of references for correct execution [129]. The aim was to use it to trigger more insights in the participants in thinking about the information and sensation carried by the positive effect of the metaphorical quality attached to this sound ("impulsing/pulling the body").

TABLE 8.4: SUMMARY OF THE SOUNDS PRESENTED IN EACH SESSION. WHEN THE "NO SOUND" VERSION WAS OPTIONAL, ALL PARTICIPANTS EXCEPT ONE CHOSE TO DO IT ANYHOW, AS THEY REPORTED THAT IT ALLOWED THEM TO BETTER UNDERSTAND AND ARTICULATE THE EFFECTS OF THE SONIFICATIONS.

Session	Sound conditions
Session 1	No sound + Wind (to allow participants to familiarize themselves with the exercises without the sound and experience one of the sounds in depth).
Session 2	No sound (optional) + Wind + Mechanical (to allow participants to relive one of the sounds and add a new one).
Session 3	No sound (optional) + Mechanical + Water (to allow participants to experience again the latter added sound and add a new one) + Tone.

In each session participants performed 1 or 2 exercises with the different sonifications selected with the aim of exploring the effect of those sounds and their characteristics in depth, and incrementally through the session eliciting further insights by comparing sounds. Out of all the exercises, the 7 participants chose squats and step-ups.

For each selected exercise, the researcher calibrated the device on the participant. The starting and ending calibration positions for each exercise. The participants were then encouraged to perform at least 3 repetitions with each selected sound condition, so participants experienced the sound more than once. After each sound condition, participants were asked to reflect on their experience and the effects of the sonification on their own BP by completing a contextual Body Map (see FIGURE 8.2) and discussing it with the researcher. At the end of each session, with all the sound conditions performed, participants were engaged in a final semi-structured interview (Appendix T) in which they were presented with all the Contextual Body Maps they had created and were asked to discuss and compare their experiences across all the sounds/exercises of that session. The whole session was audio-recorded, and also the filled-up Body Maps for analysis were kept.

8.3. Study 2: Physically Inactive People Study

The second study with physically inactive people (also referred to as Inactive People (IP) Study, TABLE 8.1), was carried out partially overlapping to Study 1 and focused on identifying potential benefits of sonification and effects of the associated sound characteristics on people who struggle with PA adherence over time in their everyday context.

8.3.1. Methods

8.3.1.1. Participants and setting

5 physically inactive people (M_{age}= 26.4, SD_{age}= 4.97, Range=21 – 33; n=5, 1 female, 4 male) who engaged in a 2-week long home study, see TABLE 8.5. Participants were recruited at Universidad Carlos III de Madrid (UC3M). The study was approved by the local ethics committee at UC3M (Appendix Q). Participants were compensated 200€, half the first and half the second week to keep their motivation to participate. They were selected (Appendix P) based on scoring moderate-low levels of PA on the IPAQ questionnaire (1290>METS/week>300) ([67]; Spanish version validated in [144]) and their availability for the study (1 hour/day for 2 weeks).

TABLE 8.5: PARTICIPANTS' INFORMATION FOR HOME STUDY.

ID	Age	Gender	PA level	Working
P1-IP	22	Male	Low	Master student
P2-IP	21	Female	Low	University student
P3-IP	27	Male	Moderate-low	Office worker
P4-IP	33	Male	Moderate -low	Office worker
P5-IP	29	Male	Low	Office worker

Exercises

Participants started with basic exercises (warm-up) followed by strength and flexibility exercises, in this order but with the freedom of performing the exercise they like for each program, as described below (Section 8.2.1.4). Over the course of the study, each participant chose an exercise from each program every day, with the possibility of repeating the exercises of the previous day or selecting a different one: warm-up program: heel lifts or bend and stretch; strength program: lateral raises (90º arm angle), leg lifts, knee lifts, or squats; and flexibility program: thigh stretch, and side arm raise (180º arm angle).

8.3.1.2. Apparatus and stimuli

a) SoniBand: mobile version

Same as in Study 1.

b) Sound stimuli

Wind, Water, and Mechanical sounds were used both in Study 1 and 2. While the "Tone" sound revealed some relevant effects in Study 1 (as shown later in results), it was not included in the study with physically inactive people, to instead include a flat tonal sound, which is named "Beep" sound, without the "pulling the body" effect described for the "Tone" sound. The aim was to use this sound as a control (or baseline) sound for participants to compare with the other "metaphorical" sounds in order to help reveal the effects of the properties of "metaphorical" sounds, thus controlling for the possible effect of simply hearing a sound while performing the same movement. TABLE 8.3 briefly describes the characteristics and metaphorical qualities of each sonification, as well as how it is designed to address psychological barriers. TABLE 8.6 provides a more detailed table with further information on the sound-movement structure of each sound.

8.3.1.3. Measures

Body Maps:

The IP study featured a simplified version of the Body Map used in the AP study and was part of the documentation that participants took home (as presented in FIGURE 8.3, Appendix U). The Body Map was simplified because the participants had the free choice about which exercise to perform, so the Body Maps had to be without exercise contextualization. This was also to avoid that people may perceive the exercise to be above their capabilities (e.g., representation of a standard squat).

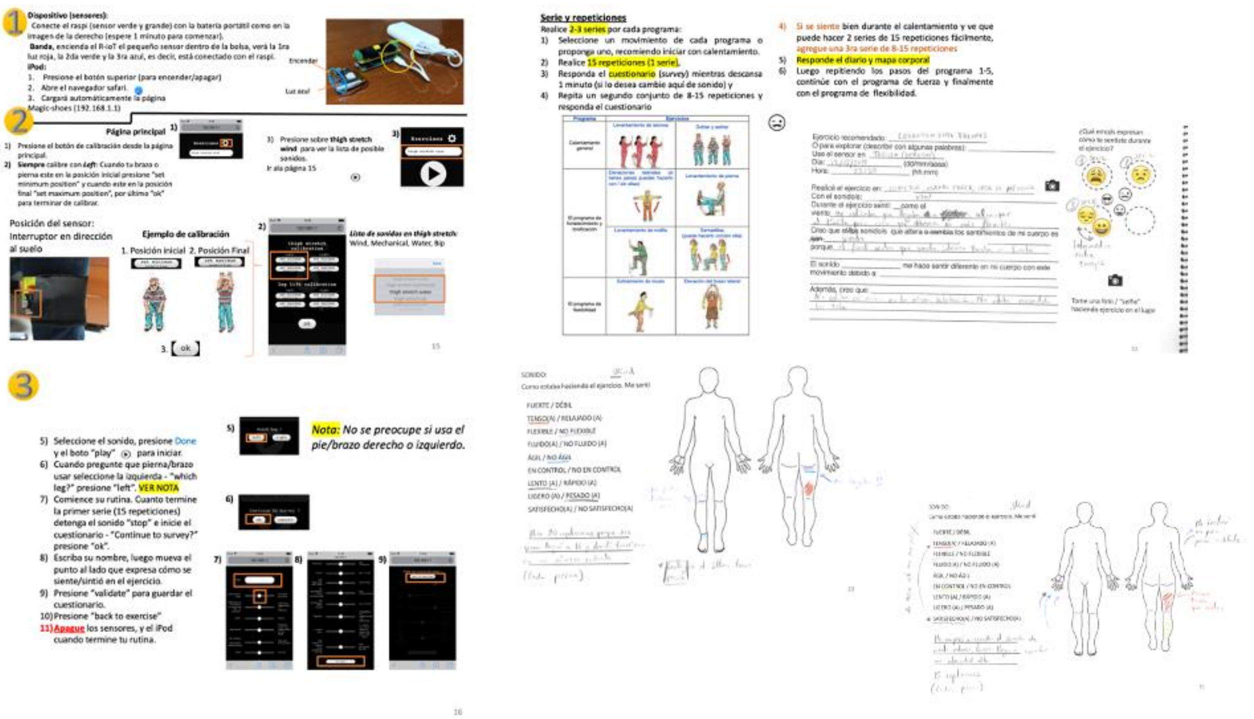

FIGURE 8.3: (LEFT) INTRUCCIONS OF THE SONIBAND WITH 3 STEPS. (RIGHT-UP) INSTRUCCIONS OF THE SELECTION OF THE EXERCISE WITH THE SERIES AND REPETITIONS. (RIGHT-CENTER) EXPLANATION OF BODY AND MOVEMENT FEELINGS OF THE PARTICIPANT. (RIGHT-DOWN) EXERCISE EXAMPLES OF HOW A PARTICIPANT USES THE BODY MAP TO REFLECT ON THEIR SENSE OF FLUIDITY, SPEED, AND CONTROL IN THE HEEL LIFTS WITH WIND SOUND.

8.3.1.4. Experimental procedure

After receiving training on how to position and calibrate the wearable for each exercise, participants engaged in daily 1-hour sessions at their home. They performed the exercises with the different sound conditions. In particular, participants were asked to select one exercise from each program, every day, starting with a warm-up exercise and one of the 4 sounds for the exercise. Depending on the exercise, participants wore the device on their ankle/thigh/arm. After calibrating the device for each movement by selecting the minimum and maximum movement position, they performed between 2 and 3 sets of 15 repetitions in each exercise. After each set, they took a rest while they answered the diary and the Body Map according to their body feelings during the exercise. They were asked to then perform a second set of 15 repetitions, and then a third set if they felt able to. The same procedure was repeated with the strengthening and flexibility programs. After each set, if they wanted, they were allowed to change the sound and hence practice with different sounds as they pleased or felt more appropriate.

At the end of each week of the IP study, they engaged in a semi-structured interview (1 hour) on their experience of using the sonification band during the week. First, the diary was reviewed to discuss the participants' thoughts and reflections during the week. Second, the Body Maps were discussed to understand what they really felt with each body property. Third, participants were asked about their reflections on the effect of sound on their exercise and body, and about the sound characteristics or properties that helped them to perform the movement. Finally, participants were asked to compare movements and sounds, for example, "*Which sound worked better with which movement?", "Which sound was more interesting or meaningful for you?* And *why?*" (See Appendix S and Appendix T).

TABLE 8.6: OVERVIEW OF THE CHARACTERISTICS OF EACH SOUND, OFFERING A GENERAL DESCRIPTION OF THE SOUND AND REFLECTING CHANGES IN THE SOUND CHARACTERISTICS (I.E., IN FREQUENCY, INTENSITY, SPEED, OR TIMBRE) AT DIFFERENT MOMENTS OF THE MOVEMENT STRUCTURE: IN THE CALIBRATED POSITIONS (START AND END OF THE MOVEMENT), OR THROUGHOUT THE MOVEMENT (TRAJECTORY). * INDICATES SOUNDS USED IN STUDY AP AND ^ INDICATES SOUNDS USED IN STUDY IP (HOME STUDY).

Sound	**Description**	**Sound-Movement Structure**		
Water*^	Continuous sound of running water, which plays during the whole movement with a “splash” sound (with different timbre) at 10% after the start/end position.	Underwater sound when stationary. Splash sound on passing 10% in calibrated movement range.	Lingering sound of water.	Splash sound at 10% of the movement range. It continues for 0.8 s after the movement ends.
Wind*^	Continuous filtered pink noise sound, imitating wind sounds, which plays uninterrupted throughout the whole movement, changing in frequency (from 600 to 1100 Hz peak frequency) in relation to angular movement.	Frequency of 600 Hz on start of movement progressively increasing in peak frequency and intensity.	Continuous sound, increasing/decreasing in frequency and intensity – depending on the movement direction.	Frequency of 1100 Hz at the last point and while the person stays still there.
Mechanical*^	Discrete sound similar to rusty gears that plays throughout the movement with gradual changes in frequency (700 – 1100 Hz) and speed.	Gears sounds play after passing 10% in the range of movement.	Discrete beeps gradually transitioning to a higher frequency and speed.	Gear sounds keep playing at highest frequency and speed as the person stays there
Tone*	A sound akin to a spring (tonal sound with fast-incremental change in frequency, from note C5 to C6), that plays a short time (0.9 s) at the start/end calibrated positions.	A spring sound - from note C5 to C6 - is triggered after passing the 10% movement range.	No Sonification.	Reverse spring sound (from note C6 to C5) triggered after passing the 10% from end to start calibrated movement range.
Beep^	Flat tone with frequency of 440 Hz sine wave) that plays only for a short time at the start/end calibrated positions.	Flat tone without changes.	No Sonification.	Flat tone without changes

8.4. Data Analysis

For both studies, a qualitative approach was used to analyze the participants' interviews, Body Maps and in the case of the IP study, their diary. The interview data were analyzed using thematic analysis [213]: first all interviews were transcribed and familiarized with the data. The transcribed data were code deductively, using the items featured in the Body Maps as codes. Simultaneously, an inductive, open coding was also performed, identifying new codes that included new bodily perceptions (e.g., "being grounded"), experiential qualities (e.g., "playful"), and the impact of sonification on the PA itself (e.g., fostering movement endurance, offering a guide on the movement, increasing movement awareness). After the individual inductive coding by two authors, the new codes and themes were shared between both, identifying similarities and differences among them, that it is used to update the coding scheme and analyze the data again. Afterward, two rounds of axial coding were performed, resulting in salient themes that revolved around emotions or possible effects of the sounds, characteristics of the sounds, and which sound worked best for them.

In the AP study, the filled-up Contextual Body Maps were revisited to substantiate and anchor the interview data in particular body parts or movement sequences; and to find possible instances where an item was selected without being explicitly referred to during the interview. In the IP study, the diary quotes written by the participants were transcribed to complement the interview analysis and to understand the body properties that the participants reflected on through the Body Maps, to clarify and understand the effect of the sound on their body or movement perception.

8.5. Results

The results encompass a variety of effects of the sonifications' on the own BP and the PA. This section focuses on findings shared between studies, qualifying differences among them, and on critical findings from the inactive population. The findings are presented under two overarching themes: impact on body and movement perception and impact on PA.

Critically, in the studies the feelings of agency over the sound that participants experienced were also assessed, as many studies have shown that the delays between actions and sensory feedback disrupt agency and diminish the sensory-induced effects in BP (e.g., [15], [60]). In both studies, participants reported that sounds supported their sense of agency, with two exceptions. Participants in the IP Study found that the water splash at the start and end of the Water (which keeps playing for a few seconds after completing the movement) affected their perceived synchronicity negatively: *"[other sounds]* *were completely in sync with my movement [...] And this one [Water] has a bit more of an after effect. So, I stopped my movement, but the sound didn't stop yet, so I didn't start my new movement until [it stopped].*" [P3-AP]. The Beep sound in the IP Study was sometimes perceived to play randomly, probably due to issues during self-calibration in participants' homes. Participants felt uncoordinated and not in synchrony "*(My thoughts during the exercise were that:) I was uncoordinated because the Beep sound did not seem to be produced by me.*" [P4-IP]. It is acknowledged that this occasional loss of agency over the sounds may have diminished or impacted on the effects on BP and PA in some cases that are highlighted in the next sections, but that at the same time they raised some interesting opportunities such as the impact on movement perception and PA.

8.5.1. Body sensations and participants profiles in Study 2 (lP-study or long-term home study)

This section presents the general body sensations and profiles of physically inactive participants. First, it is presented the percentage of the time that the body sensations were felt when listening to a sound; these body sensations were collected from the Diary that participants filled every day. Participants' profiles were created based on the interviews to choose the participants of the study while in Study 1 were just identified by the PA level, here to know the routines of the participants allows us to know if the possible reasons of the physical inactivity are related to negative body perceptions. The first aim of the interviews was to get to know their possible barriers that prevent their involvement in PA [6] (see Appendix V). The second aim of the interviews was to understand their everyday activities, relaxation activities, and other barriers not covered by the survey.

Lastly, participants were also introduced to the SoniBand device and setup, and feedback options were explained. Participants were supported in calibrating the device for the exercises and how to set a starting position and a maximum body position.

8.5.1.1. Body sensations per sound during the home study

During the IP study, participants performed around 300 to 690 repetitions with each sound, see TABLE 8.7. During the *Warm-Up* program, with the sound of Wind in 23.81% of the repetitions, the participants felt light. In addition, with the Water sound in 21.62% of the repetitions of the participants felt strong, in 27.03% of the repetitions felt relaxed, in 29.73% of the repetitions felt flexible, in 24.32% of the repetitions they felt in control, and in 40.54% of the repetitions they felt satisfied with the exercise.

When performing exercises from the *Flexibility* program (TABLE 8.7), with the “Wind” sound, in 44.74% of the repetitions performed the participants felt strong with the sound; they felt light in 34.21% of the repetitions, and in 31.58% they felt satisfied. With the “Mechanical” sound, during the repetitions of the sound, they felt strong (40%), flexible (20%), without agility (20%), but satisfied (50%). With the “Water” sound, participants felt strong (25.58%), flexible (25.58%), light (23.26%), and satisfied (34.88%) during repetitions of these exercises. It is worth mentioning that without sound in some of the repetitions (26.09%) they felt heavy, see TABLE 8.7.

When performing exercises from the *Strengthening* program (TABLE 8.7), participants felt light (25%) and satisfied (22.22%) with the “Wind” sound; with the “Mechanical” sound the participants felt in control (33.33%), they also felt light (20.83%), heavy (25%) and satisfied (33.33%), see TABLE 8.7.

It is worth mentioning that with the “Beep” sound there were feelings of weakness (in program of *Flexibility = 20%*) and heaviness (*Strengthening = 34.29%*), and in all three programs participants were dissatisfied (*Warm-Up = 37.93%*, *Flexibility = 40%*, and *Strengthening = 40%*), although in the Flexibility program participants felt satisfied in 20% of the repetitions, see TABLE 8.7 and FIGURE 8.4 which shows only percentage per sound.

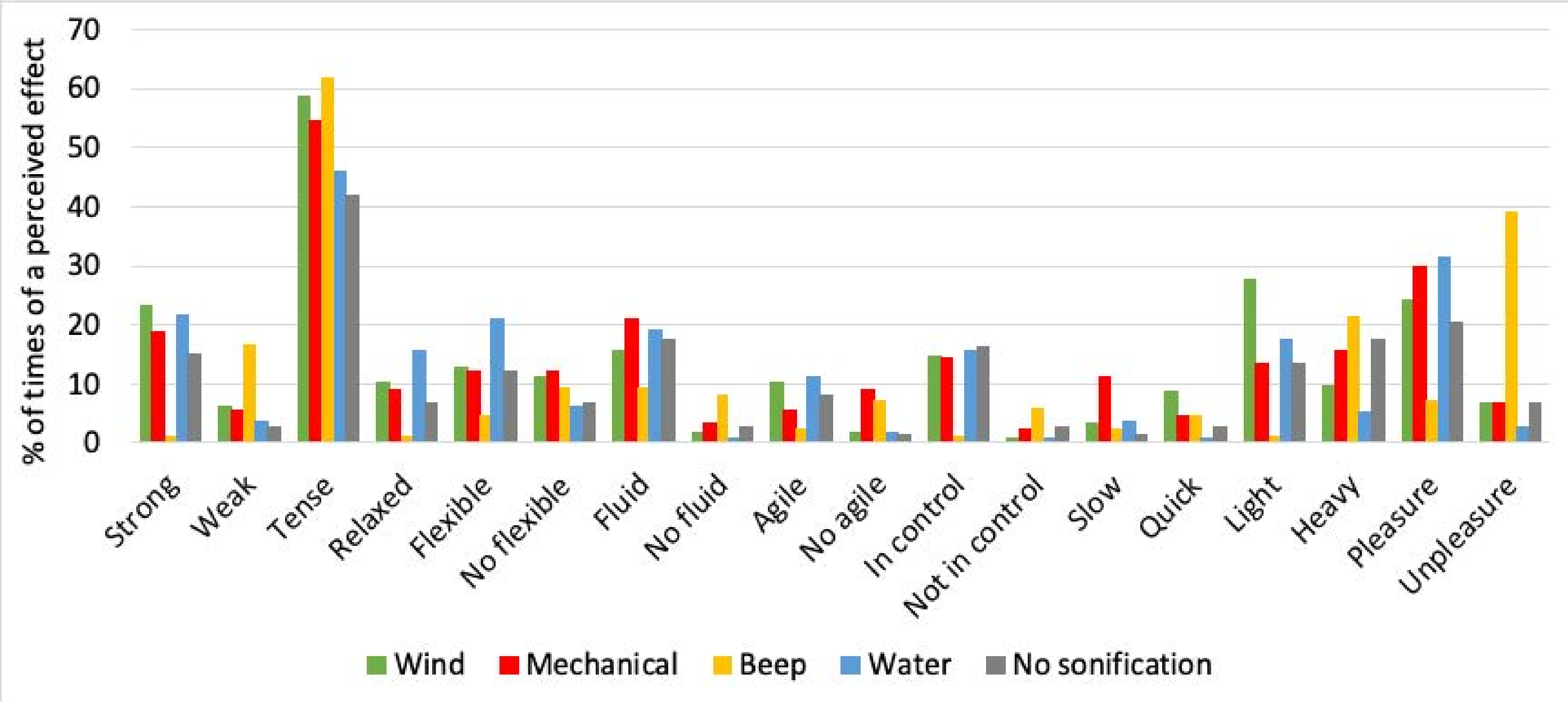

FIGURE 8.4: PERCENTAGE OF TIMES THAT THE PARTICIPANTS PERCEIVED A BODILY SENSATION OR EMOTIONAL FEELING WITH EACH SOUND.

TABLE 8.7: PERCENTAGE OF TIMES THAT THE PARTICIPANTS PERCEIVED A BODILY SENSATION DURING EACH SERIES (15 REPETITIONS), NS = NO SONIFICATION, RED COLOR INDICATES HIGHE VALUES.

Program	Warm-Up					Flexibility					Strengthening				
Scales/ Sound	**Wind**	**Mechanical**	**Beep**	**Water**	**NS**	**Wind**	**Mechanical**	**Beep**	**Water**	**NS**	**Wind**	**Mechanical**	**Beep**	**Water**	**NS**
Strong	14.29	8.33	0	21.62	13.79	44.74	40	5	25.58	13.04	11.11	16.67	0	17.14	18.18
Weak	11.9	8.33	17.24	2.7	3.45	0	0	20	4.65	4.35	5.56	16.67	14.29	2.86	0
Relaxed	14.29	13.89	0	27.03	17.24	15.79	10	5	11.63	0	0	0	0	8.57	0
Flexible	21.43	8.33	3.45	29.73	20.69	5.26	20	0	25.58	0	11.11	8.33	8.57	5.71	13.64
No Agile	4.76	2.78	17.24	2.7	3.45	0	20	0	2.33	0	0	4.17	2.86	0	0
In Control	14.29	16.67	0	24.32	20.69	10.53	10	5	11.63	8.7	19.44	33.33	0	11.43	18.18
Light	23.81	11.11	3.45	16.22	17.24	34.21	16.67	0	23.26	4.35	25	20.83	0	11.43	18.18
Heavy	4.76	19.44	17.24	5.41	10.34	18.42	16.67	5	0	26.09	5.56	25	34.29	11.43	18.18
Pleasure	19.05	22.22	3.45	40.54	37.93	31.58	50	20	34.88	8.7	22.22	33.33	2.86	17.14	9.09
Unpleasure	2.38	5.56	37.93	0	0	15.79	6.67	40	2.33	8.7	2.78	16.67	40	5.71	13.64
Series (total)	42	36	29	37	29	38	30	20	43	23	51	34	34	46	20
Series*Reps	630	540	435	555	435	570	450	300	645	345	765	510	510	690	300

8.5.1.2. P1: profile and body sensations in the IP study

P1 is a master's student and works in a laboratory at the university. His daily routine consists of attending his master's classes and working on the class and lab projects and traveling by public transport/walking from home to the university. He does not have the routine of doing any sport, because he doesn't feel motivated; he says, "it does not come out of me". Moreover, he mentioned that since he started to study at the university 5 years ago, he prioritizes his studies over sports. His possible motivations for doing PA could be performing sports as part of a team. His favorite sport is Hockey because it is played with a stick. Even when he hasn't played hockey in 6 or 7 years, he says that if he had the expensive material and access to the facilities to play, he would play once or twice a week. He uses a device, called "Mi Band", to receive feedback about his PA. This device is connected to a mobile application "Mi Fit". He checks the distance traveled in the day and sometimes the sleep patterns. He has set a goal using this app of completing 8,000 steps per day (around 5 km). He is familiar with smartphones and apps, so the use of the prototype is not a problem for him.

Figures below show the percentage of times that P1 reported a felt body quality using the diary during the IP study. The marker points on the graph indicate the body sensations. FIGURE 8.5 shows that on day 1, the sound of "Wind" made participant P1 feel light, in control, and all the time fluid in the "lateral 180°" movement, compared to day 12 in which he performed the same movement but the sensations, such as feeling light, strong, relaxed or in control, were present more times except for the feeling of fluidity that was present only the first day. As noted, the sensation of tension was commonly related to muscle tension. These sensations seem to be positive because the feeling of satisfaction was present during most of the study. On the other hand, it seems that the "lateral 90º" movement together with the "Wind" sound did not evoke a pleasant sensation; with this movement, P1 reported feelings of heaviness, tension, and no flexibility; moreover, this can also be seen in that the participant chose not to perform this movement with other sounds (see FIGURE 8.6, FIGURE 8.7, FIGURE 8.8).

With the "Mechanical" sound, on day 1, P1 felt light, relaxed, and agile with the 180º squat and lateral movements; in addition, for the latter movement, a sense of fluidity was added. These emotions were also shown on day 10, in which a sense of control was also reported with the same 180º lateral movement (see FIGURE 8.6).

On day 1, the sound of “Water” made P1 feel strong, weak, flexible, fluid, heavy, and satisfied. On days 7 and 11 with the same movement (heel lift) the participant felt relaxed, flexible, light and satisfied, adding the sensation of strength on day 11. This could be due to the fact that on the first day the participant went through a learning phase, but as the days passed, he was able to focus more on his sensations (See FIGURE 8.7).

With the “Beep” sound, on day 1, P1 felt fast when performing squats, and on day 2 felt flexible, light, and satisfied. From day 3 onwards it seems that most of the time the participant felt heaviness, weakness, and dissatisfaction with this sound (See FIGURE 8.8.)

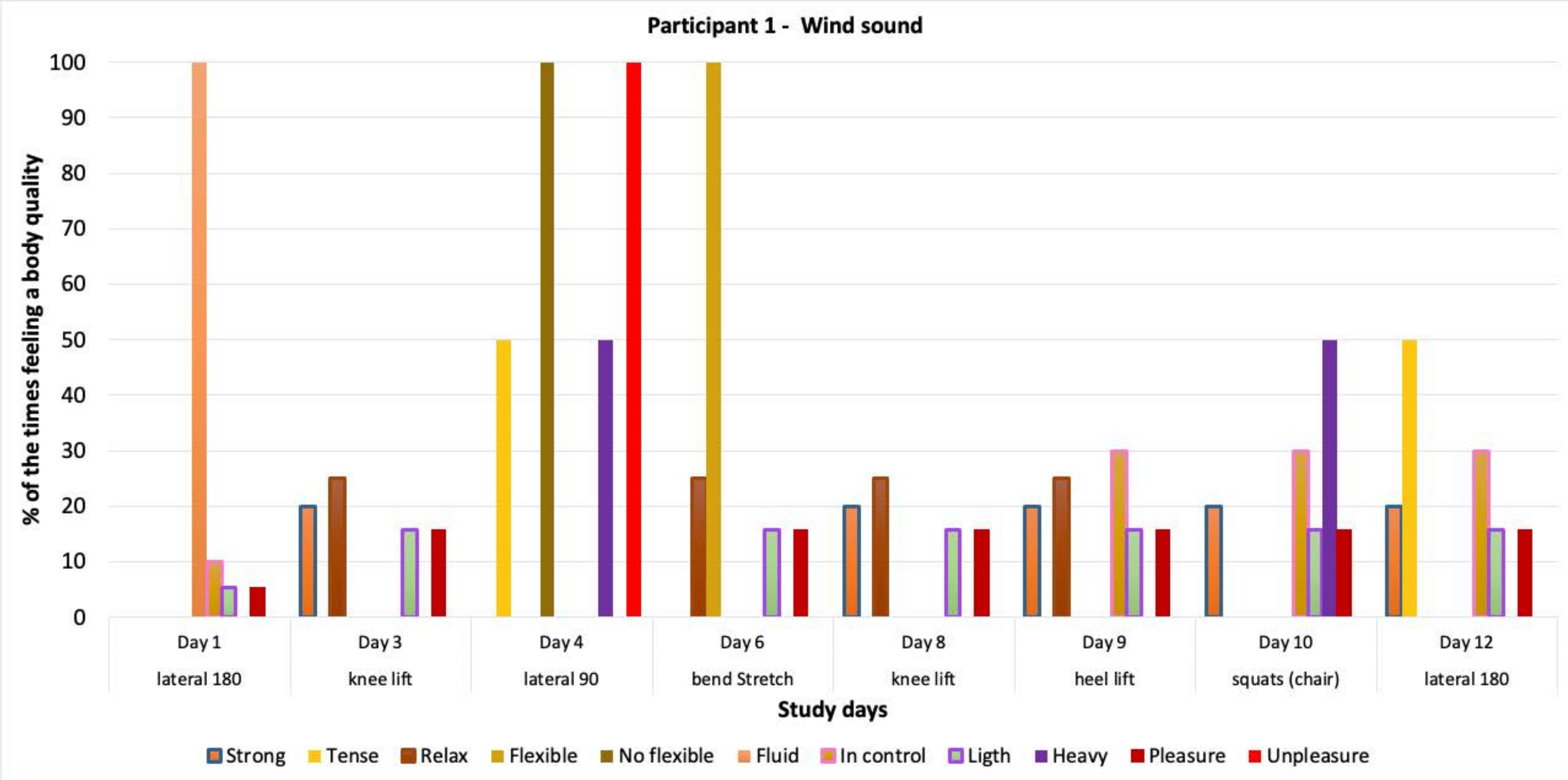

FIGURE 8.5: GRAPH SHOWING BODY SENSATIONS ELICITED BY THE WIND SOUND DURING THE IP STUDY FOR PARTICIPANT P1. THE LIST OF BODY SENSATIONS WAS RECONSTRUCTED FROM THE DIARY.

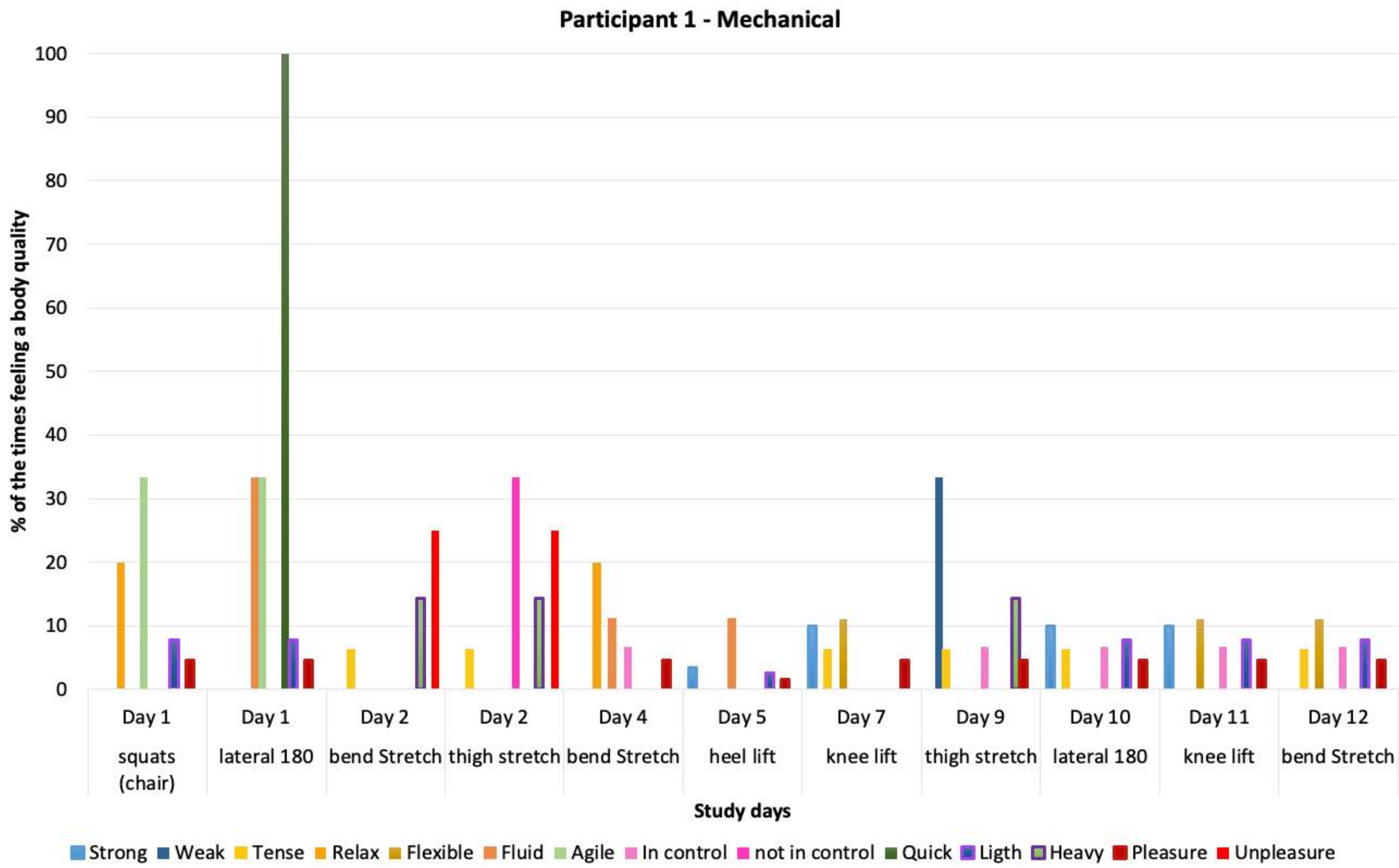

FIGURE 8.6: GRAPH SHOWING BODY SENSATIONS ELICITED BY THE MECHANICAL SOUND DURING THE IP STUDY FOR PARTICIPANT P1. THE LIST OF BODY SENSATIONS WAS RECONSTRUCTED FROM THE DIARY.

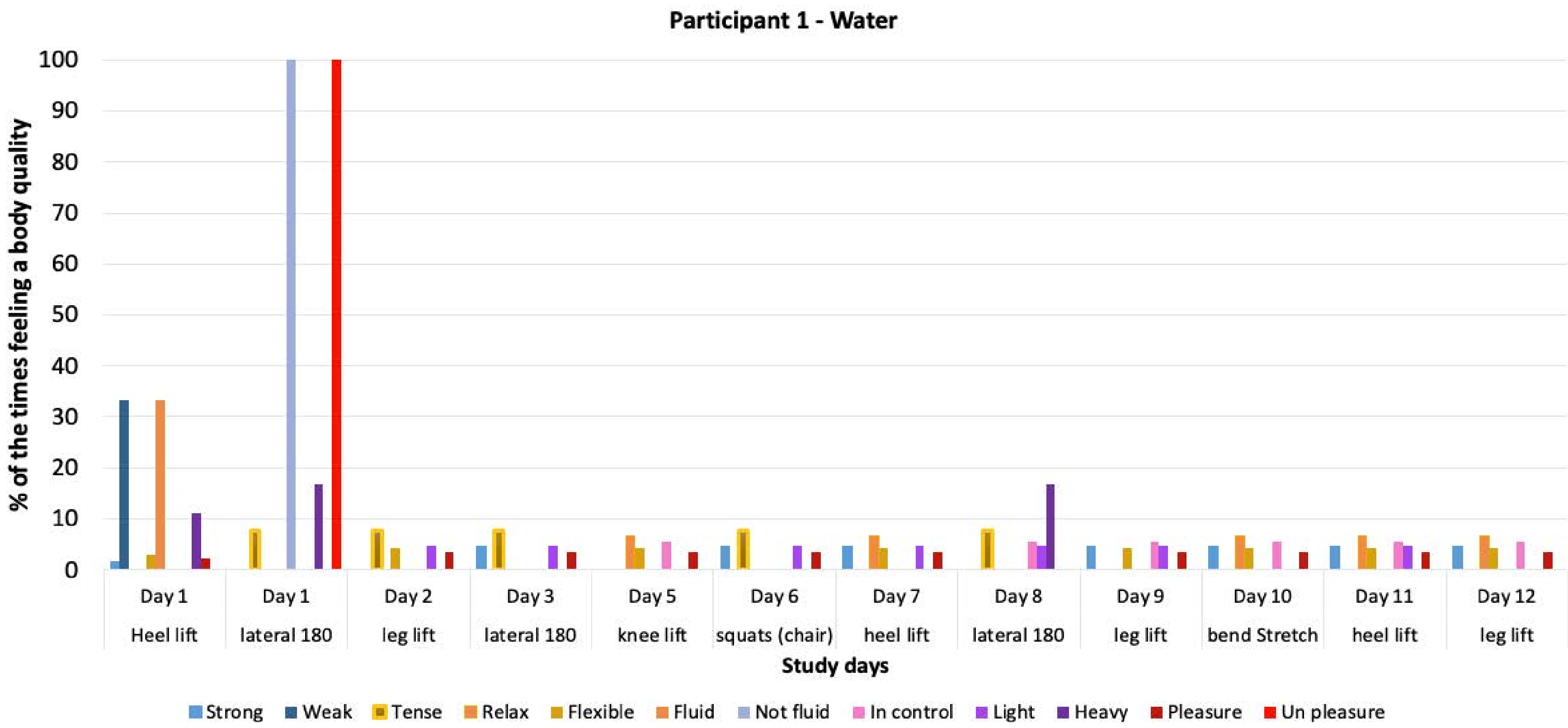

FIGURE 8.7: GRAPH SHOWING THE BODY SENSATIONS ELICITED BY THE WATER SOUND DURING THE IP STUDY FOR PARTICIPANT P1. THE LIST OF BODY SENSATIONS WAS RECONSTRUCTED FROM THE DIARY.

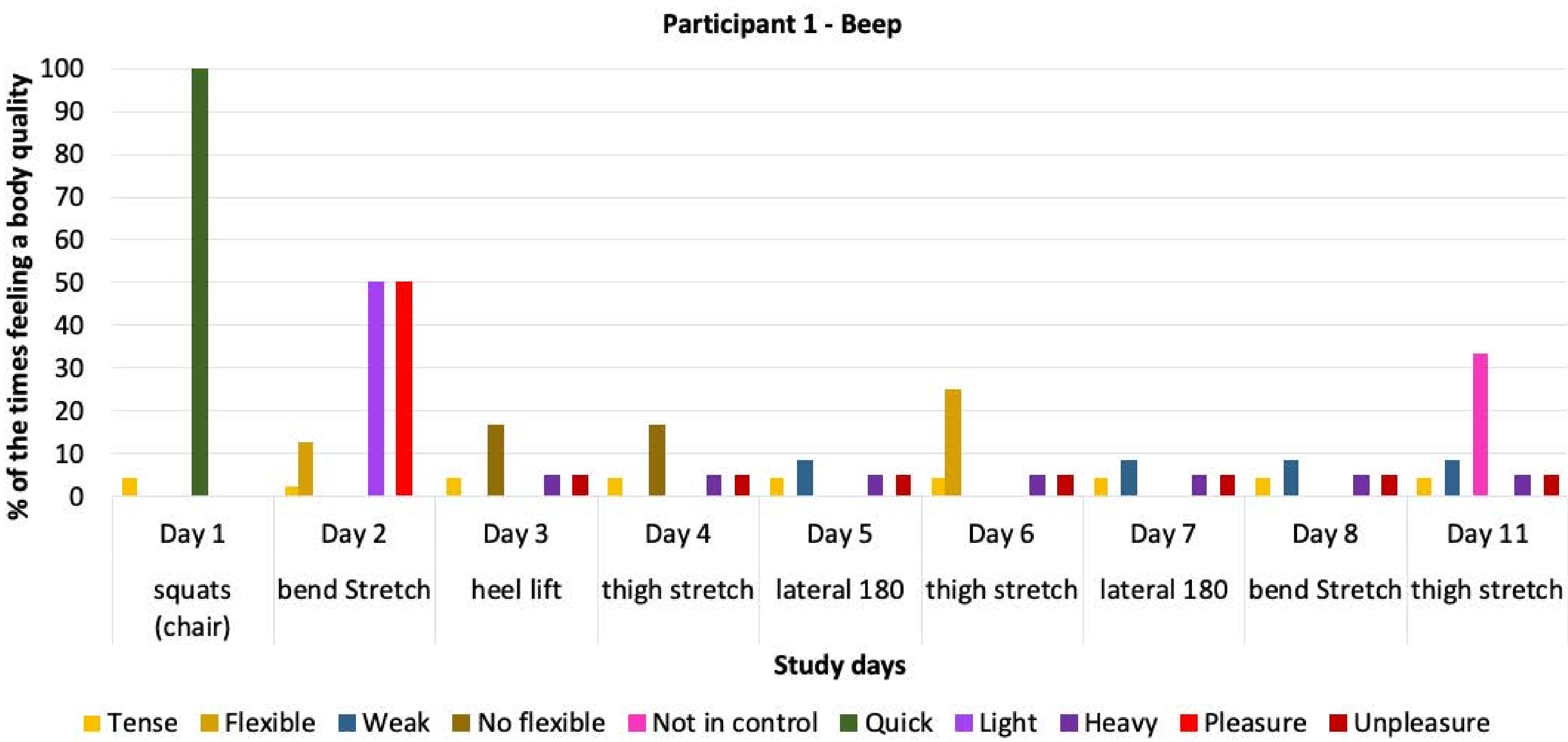

FIGURE 8.8: GRAPH SHOWING BODY SENSATIONS ELICITED BY THE BEEP SOUND DURING THE IP STUDY FOR PARTICIPANT P1. THE LIST OF BODY SENSATIONS WAS RECONSTRUCTED FROM THE DIARY.

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8.5.1.3. P2: profile and body sensations in the IP study

P2 is a university student. Her daily routine involves classes at the university, using her mobile phone or watching TV during her free time, and taking English classes; on the weekend she spends her time hanging out with her friends, staying at home, or visiting her town. She hasn't practiced PA regularly since high school when she had compulsory PA classes. Her barriers that prevent PA relate to feeling **lazy**, **tired**, and bored to exercise, that is, she doesn't feel motivated to perform PA. She doesn't know how to engage on PA; she feels a **lack of strength**. She finds excuses, for instance, the weather in summer is too hot and winter is too cold. She prioritizes other activities (e.g., studies), and postpones PA and housework (e.g., ironing clothes), so that she decides just to perform one of them, PA or housework. She doesn't like to feel obligated to perform PA, for instance, her uncle tells her "<Participant name> *go and do something*" instead of inviting her *"¡let's go (vamonos)*!", she would like the idea to emerge from her. She has been thinking about doing PA since a year ago, for instance, 3 days per week, 30 minutes. She likes individual sports (e.g., swimming), or group classes at the gym (e.g., zumba), or competition sports (e.g., ping pong).

P2 felt a lack of flexibility with "Wind" and "Mechanical" sounds (see FIGURE 8.9and FIGURE 8.10). In addition, it is worth mentioning that for her a sense of tension (related to muscular tension) and weakness was present with the 3 sounds ("Wind", "Mechanical", and "Beep"). Considering this, with the "Wind" sound on day 1, P2 felt slow and heavy; on the other days, P2 reported feeling sometimes unpleasant, not agile, and not in control. Likewise, with the "Mechanical" sound, P2 kept feeling a lack of flexibility, which was accompanied by feelings of heaviness, slowness, and pleasure on some occasions (see FIGURE 8.10).

On the other hand, with the "Water" sound, P2 reports showed that after having used the sound for several days, the feeling of lack of flexibility transformed to the feeling of being flexible and satisfied in at least one exercise (thigh stretch). In addition, P2 felt most days relaxed, and on some occasions, in control, slow, and quick (see FIGURE 8.11 below).

In the case of the "Beep" sound (FIGURE 8.12), the feeling of lack of flexibility was present in two days. There were several body sensations present throughout the study, for instance, on day 2 with the "leg lift" movement, P2 felt all the time in control, slow, weak, and heavy; but there was a sense of unpleasantness with the interaction. It should be noted that, on day 5, this feeling of unpleasantness remained with the same movement. On the other hand, for P2 the sense of unpleasantness changed to pleasure on day 9, feeling, likewise day 11 and 15 with a sense of weakness but on day 11 there was a sense of control over the movement. This allows observing that the "Beep" sound seems to work better with squats than with the leg lift movement.

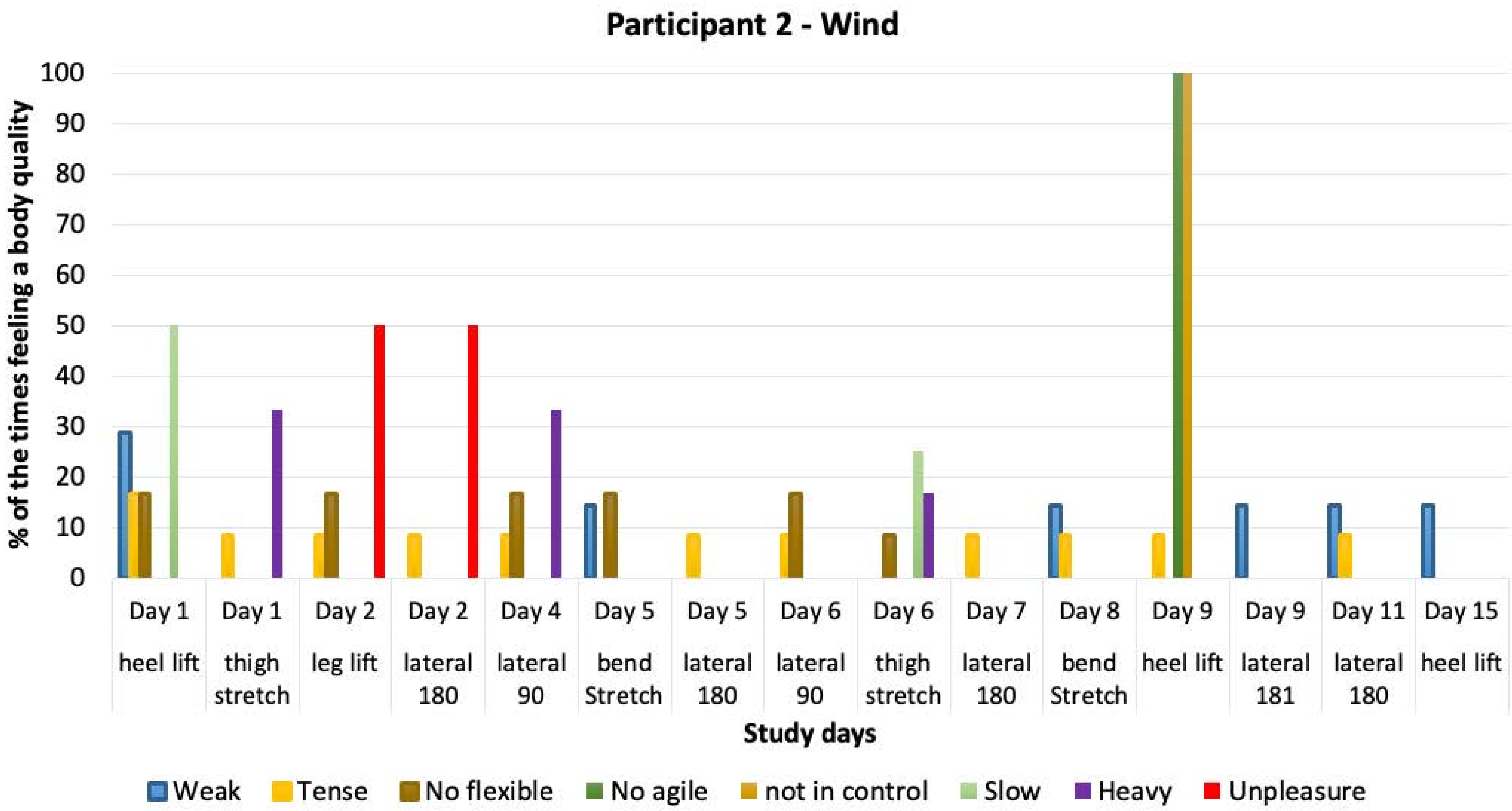

FIGURE 8.9: GRAPH SHOWING BODY SENSATIONS WITH THE WIND SOUND DURING THE HOME STUDY FOR PARTICIPANT P2.

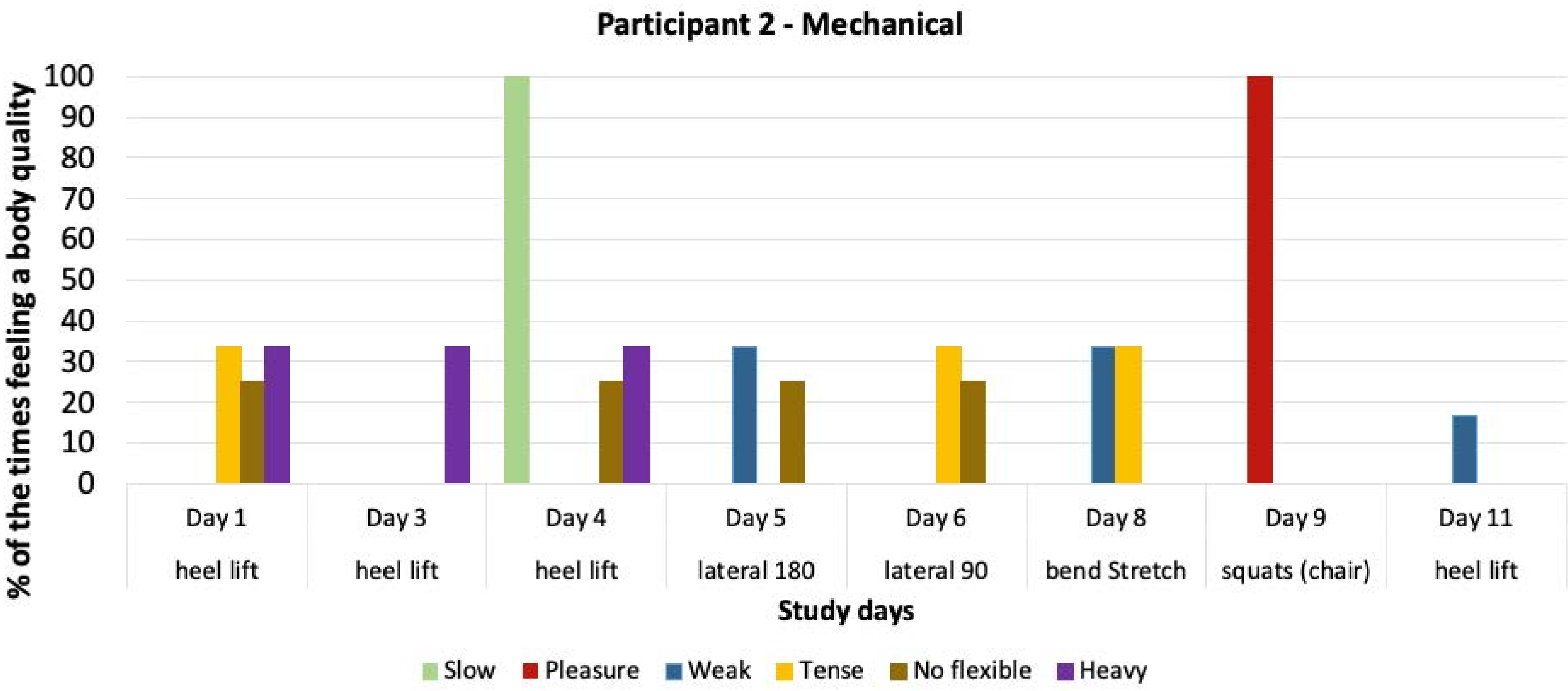

FIGURE 8.10: GRAPH SHOWING BODY SENSATIONS WITH THE MECHANICAL SOUND DURING THE HOME STUDY FOR PARTICIPANT P2.

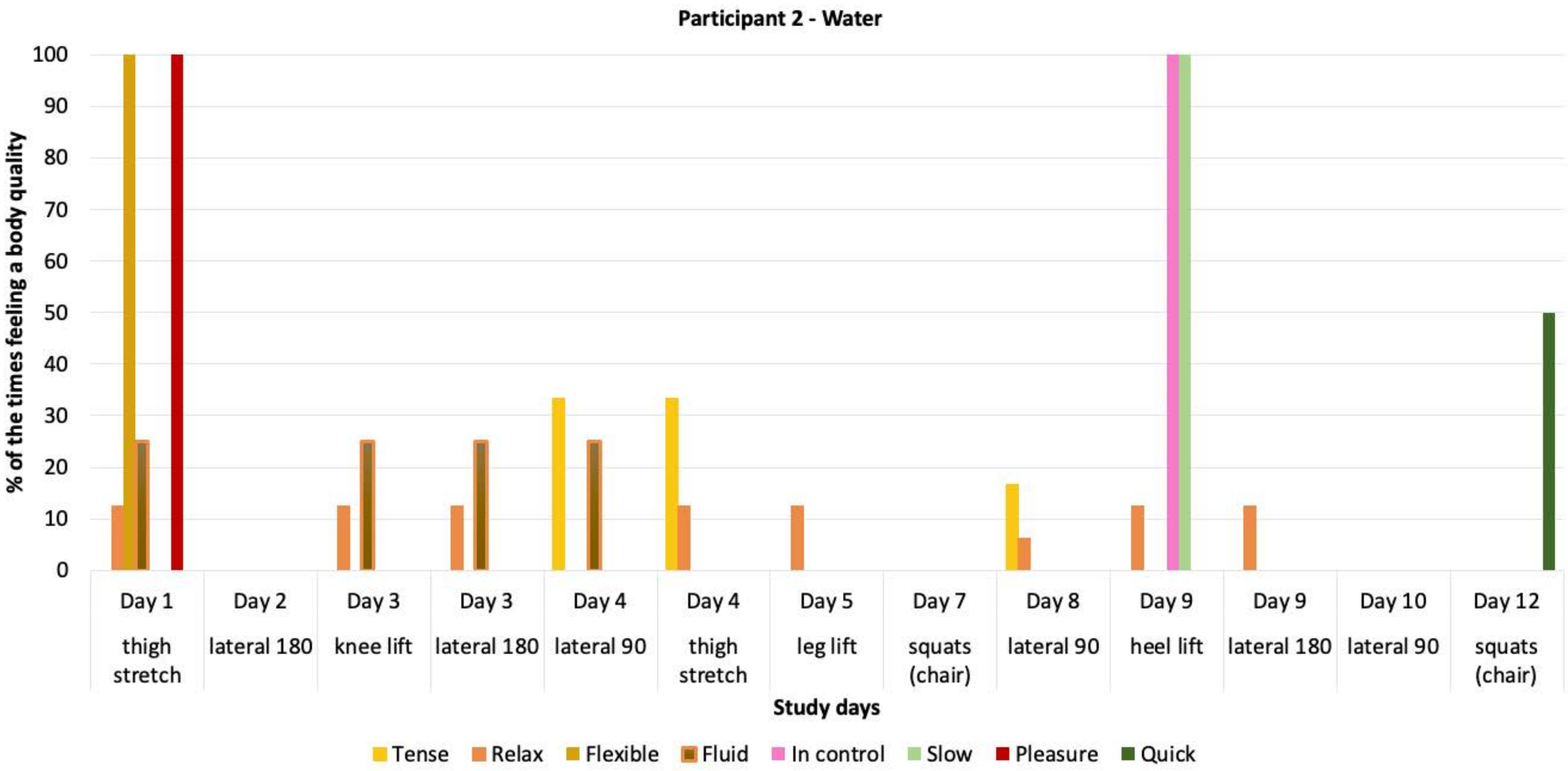

FIGURE 8.11: GRAPH SHOWING BODY SENSATIONS WITH THE WATER SOUND DURING THE HOME STUDY FOR PARTICIPANT P2.

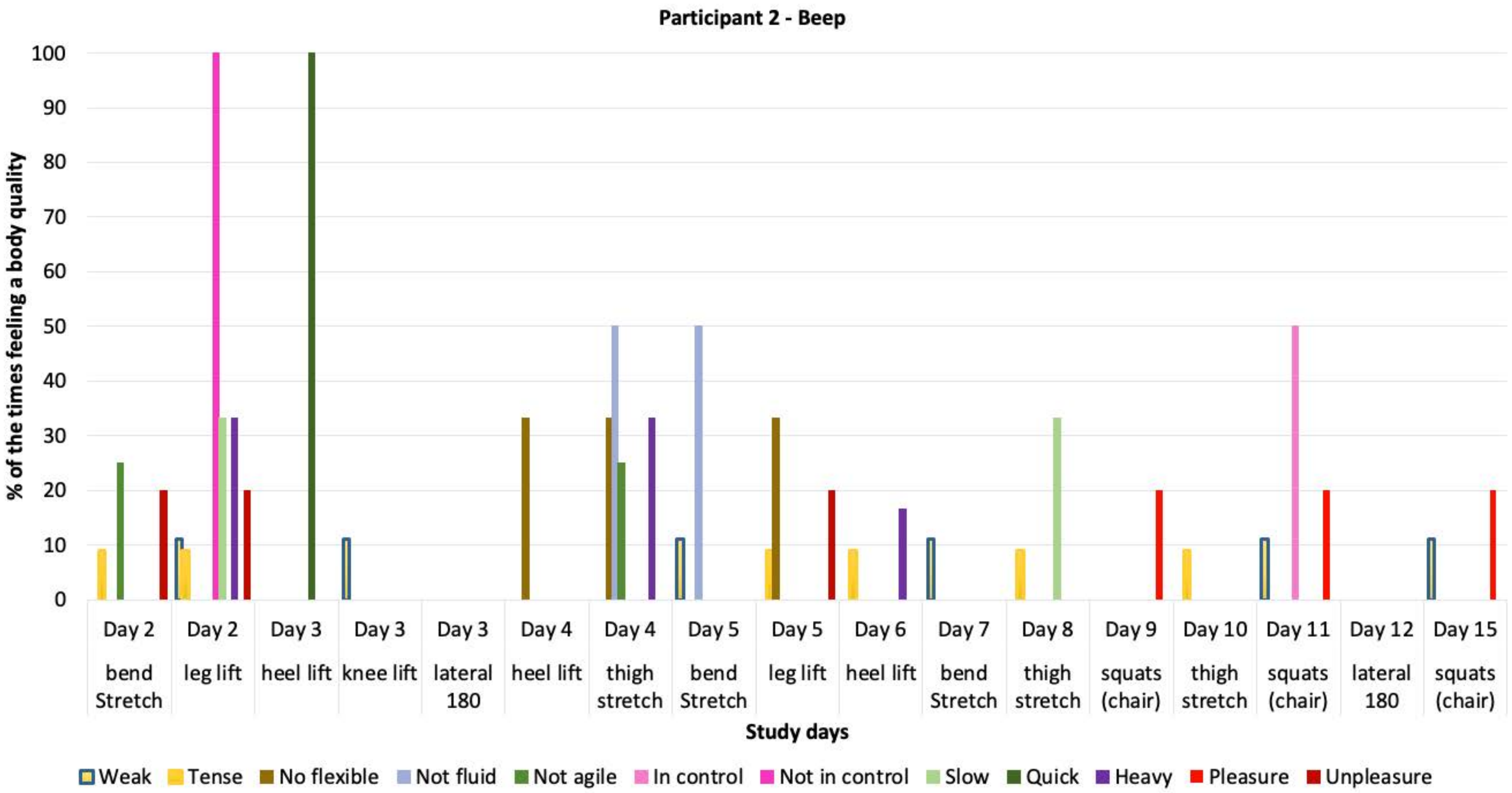

FIGURE 8.12: GRAPH SHOWING BODY SENSATIONS WITH THE BEEP SOUND DURING THE HOME STUDY FOR PARTICIPANT P2.

8.5.1.4. P3: profile and body sensations in the IP study

P3 is an office worker and works in an office/laboratory of the university. His daily routine consists of working at the university, using the train, and walking from home to the university. He does not have the routine of doing any sport. His barriers are that he prioritizes doing other things than sport or PA, e.g., housework or having fun with friends. He says, "*I'd rather spend my time with other people than go jogging down the street alone*". His favorite sport is Airsoft, he considers it an expensive sport in which a battle with firearms replicas, that shoot plastic balls, is simulated; he says that if he had the expensive material or if it was cheaper, he would play once or twice during the weekend. He also uses "Mi Band" and the mobile application "Mi Fit". However, he only checks the sleep information. He is familiar with technology, like smartphones and games in apps of all types, e.g., RPG and "candy crush", therefore he does not have problems with new technology.

For the "Wind" sound, on day 1, it seems "Wind" does not evoke to P3 other feelings apart from unpleasantness (FIGURE 8.13). From day 2 to day 7, there were several body sensations that emerged, like fluidity and lightness, which are interpreted as positive due to the pleasure sensation that accompanied them. Since day 8, the sense of agility was the most present sensation in the exercises, adding the sensations of being flexible and no flexible in two days, and the feelings of pleasure and being in control on the last day.

For "Mechanical" (FIGURE 8.14), as for the "Wind" (FIGURE 8.13) sound, on day 1 the sound didn't evoke any body sensations. However, on day 4, P3 reported feeling not fluid, not agile, and unpleasant. These body sensations are repeated in the remaining days (FIGURE 8.14). In contrast, for the "Water" sound, from day 1, P3 felt in control and light, keeping both sensations until day 4. Also, with the "Water" sound on days 2 and 3, P3 felt fluidity, agility, and slowness. P3 highlighted the feelings of agility and pleasure almost every day (FIGURE 8.15).

Lastly, the "Beep" sound did not evoke body sensations, but P3 reported feeling satisfied with this sound, with an exception last day (see FIGURE 8.16).

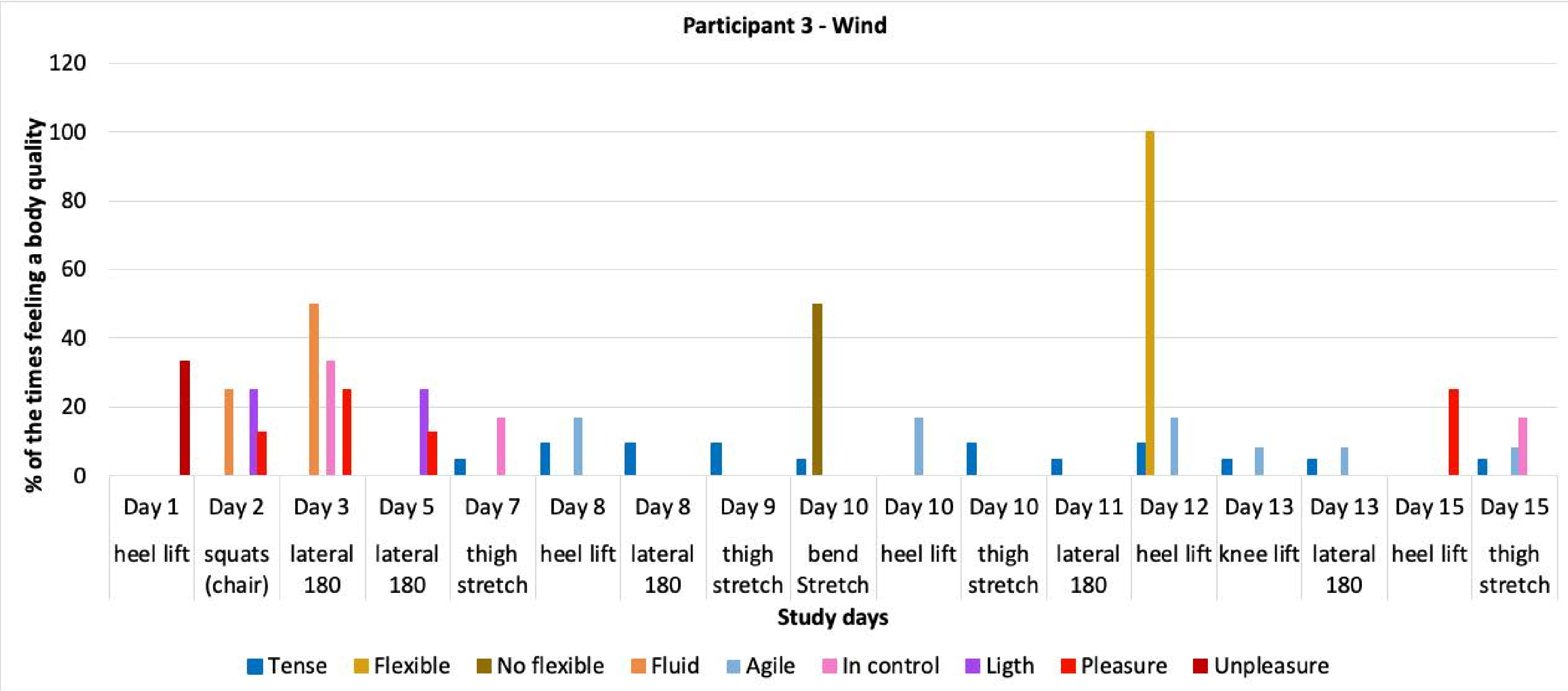

FIGURE 8.13: GRAPH SHOWING BODY SENSATIONS WITH THE WIND SOUND DURING THE HOME STUDY FOR PARTICIPANT P3.

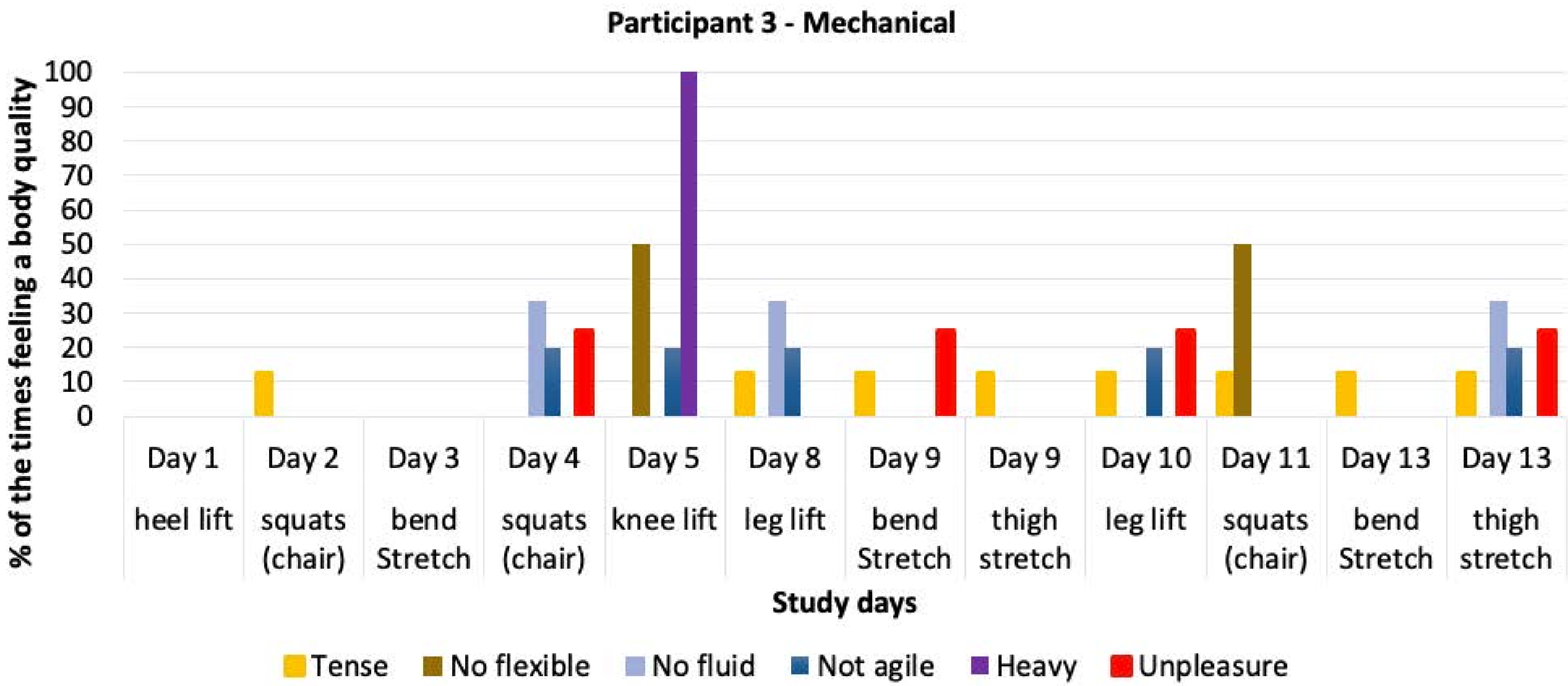

FIGURE 8.14: GRAPH SHOWING BODY SENSATIONS WITH THE MECHANICAL SOUND DURING THE HOME STUDY FOR PARTICIPANT P3.

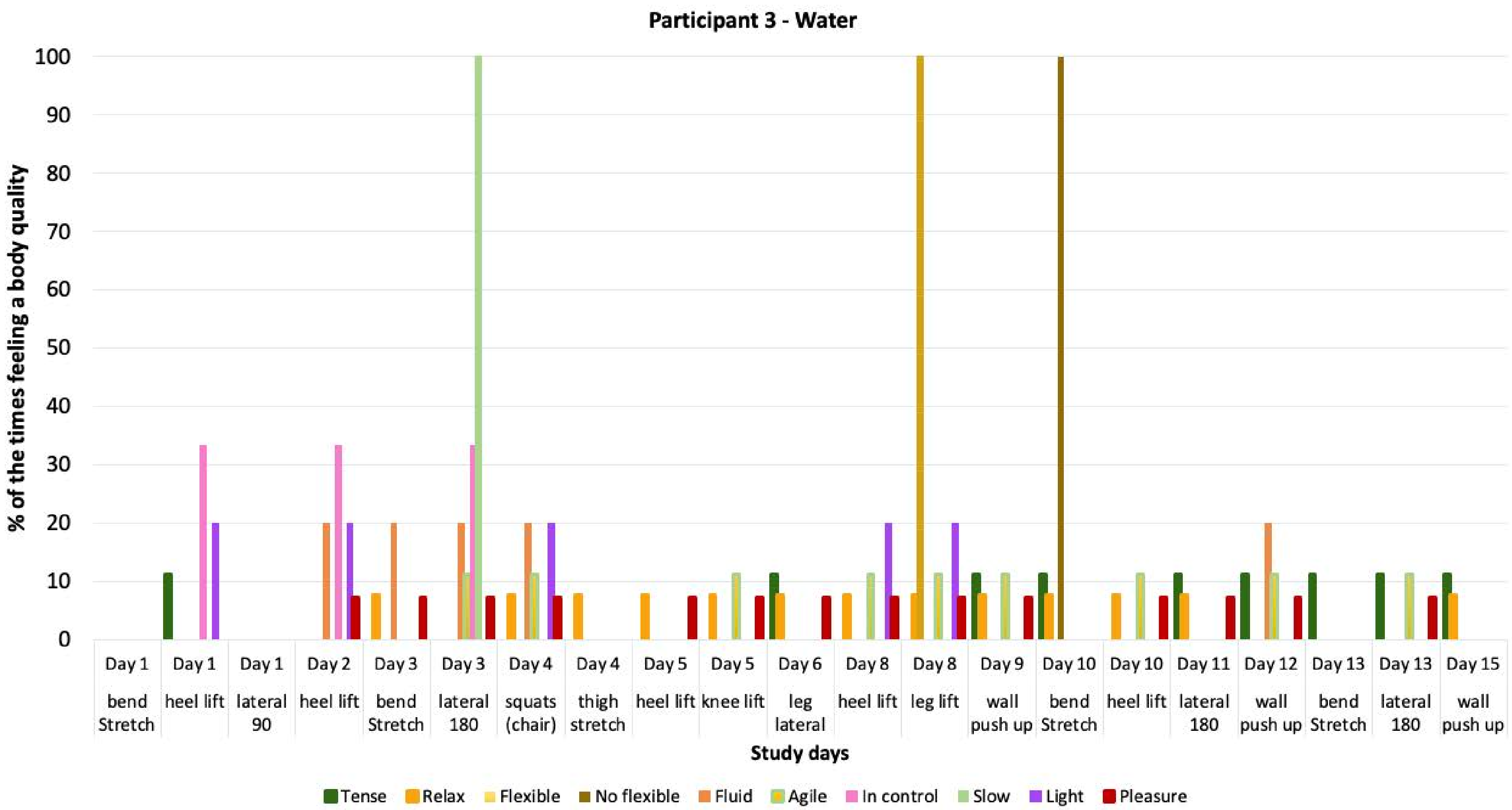

FIGURE 8.15: GRAPH SHOWING BODY SENSATIONS WITH THE WATER SOUND DURING THE HOME STUDY FOR PARTICIPANT P3.

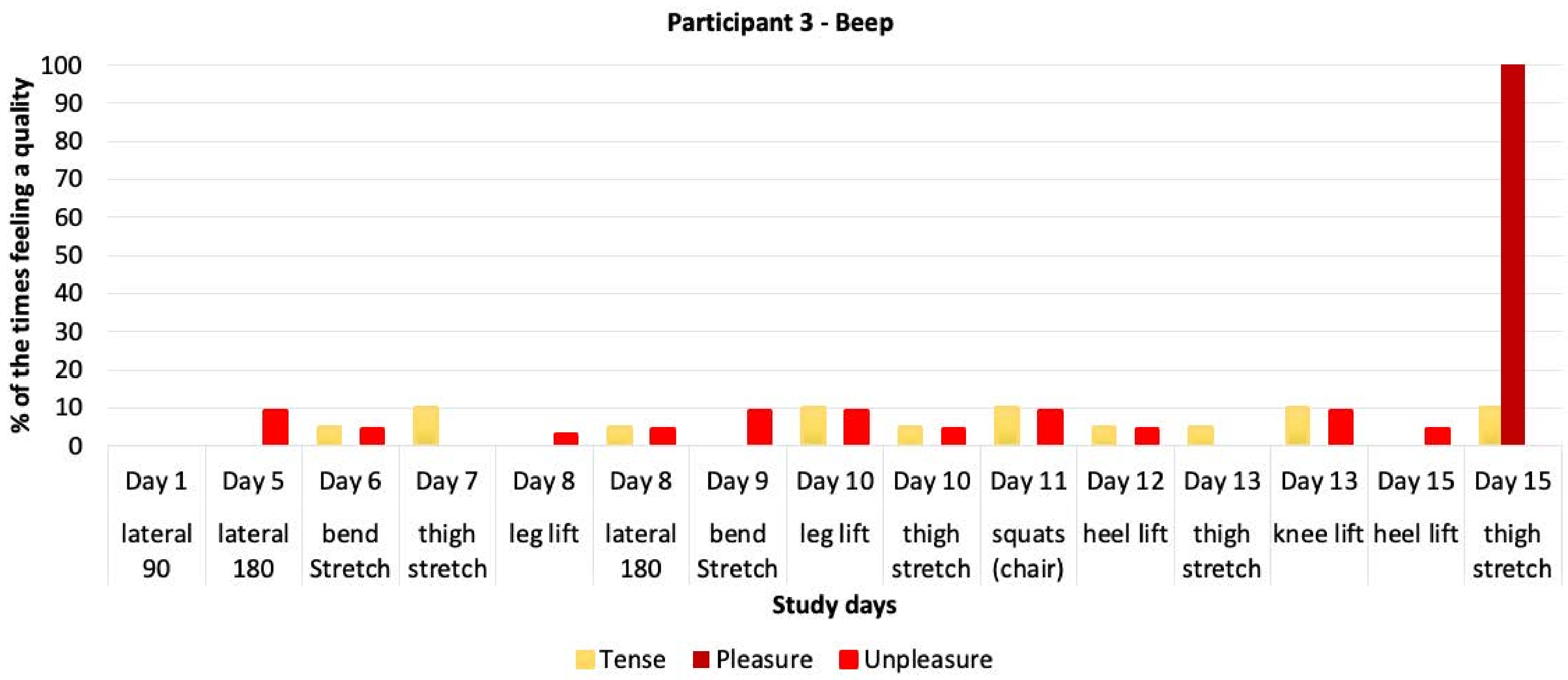

FIGURE 8.16: GRAPH SHOWING BODY SENSATIONS WITH THE BEEP SOUND DURING THE HOME STUDY FOR PARTICIPANT P3.

8.5.1.5. P4: profile and body sensations in the IP study

P4 is an office worker and works in an office/laboratory of the university. His daily routine consists of working at the university, walking from home to the university and back, staying at home, cooking, reading, or sometimes spending time with his car on the weekend. He does not have a routine of doing exercise recently. He hasn't cycled for five years; he has mainly stopped exercising since he moved in with his girlfriend. He mentioned the only activity with an extra effort is when he is cleaning and waxing his car. The barriers that prevent his PA are related to prioritizing other activities (e.g., reading or creating electronic gadgets), weather (e.g., cold), lack of motivation, stress, he doesn't feel fit. The last one talks about a chain of sensations, he can't find the moment, then he loses his physical condition when he changes his mind and tries doing again PA, for example, the day he takes the bike, he gets tired quickly, and he says, *"I'll start little by little"*, however, in the end, he leaves it again. Lastly, he noted that at the end of the day he felt too tired even when his activities do not require effort.

With the "Wind" sound, P4 reported several body sensations and it was not possible to observe the changes through a figure, due to a misunderstood of the instructions. For the "Mechanical" sound (FIGURE 8.17), on day 1, P4 felt weak and slow. On day 2, P4 felt strong and pleasure, but with lateral 90º felt a lack of flexibility, heavy, slow, and with no control over the movement. From day 4 to day 12, P4 felt heavy but strong, and sometimes without agility. It should be noted that the "Mechanical" sound seems to work in harmony for P4 with the thigh stretch exercise, as it can be seen that with this sound and exercise P4 felt flexible, strong, light, and agile on days 3 and 4 (FIGURE 8.17).

For the "Water" sound, the body sensations seemed positive for the different exercises (FIGURE 8.18FIGURE 8.18). For instance, on day 1, P4 felt slow and strong with "leg lift"; and P4 felt fluid and light with "thigh stretch". On day 9 with leg lift, P4 felt flexible, fluid, and pleasure; moreover, with "thigh stretch", P4 felt fluid, agile, and strong. On day 12 the fluidity remains and the feeling of being heavy is added. However, during the "squats" movement, with the "Water" sound P4 perceived himself as not flexible and not agile, but at the same time with a sense of fluidity, while feeling unsatisfied in all the repetitions (FIGURE 8.18).

In the case of the “Beep” sound, P4 explored the sound in just 4 days. On day 1, P4 felt strong, relaxed, and quick but unpleasant. On the other 3 days, P4 felt without flexibility, fluidity, and control (FIGURE 8.19).

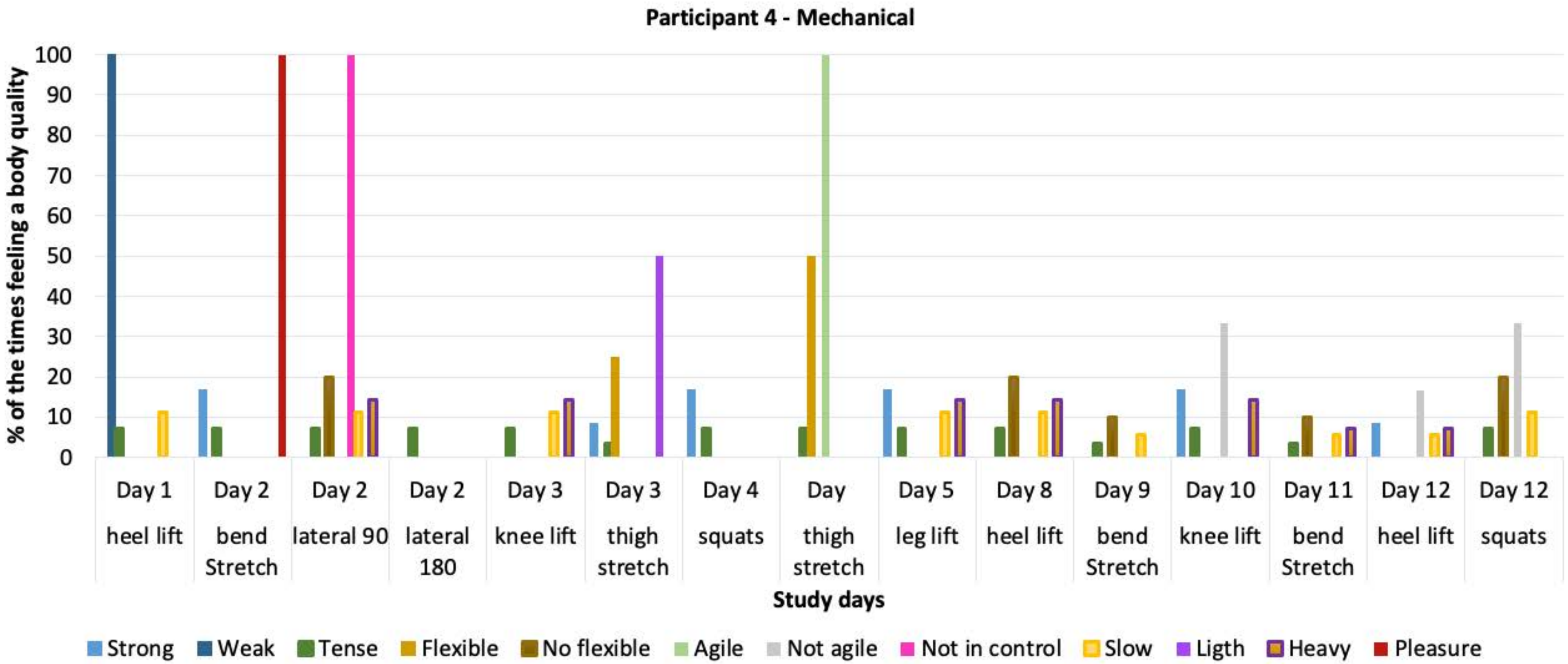

FIGURE 8.17: GRAPH SHOWING BODY SENSATIONS WITH THE MECHANICAL SOUND DURING THE HOME STUDY FOR PARTICIPANT P4.

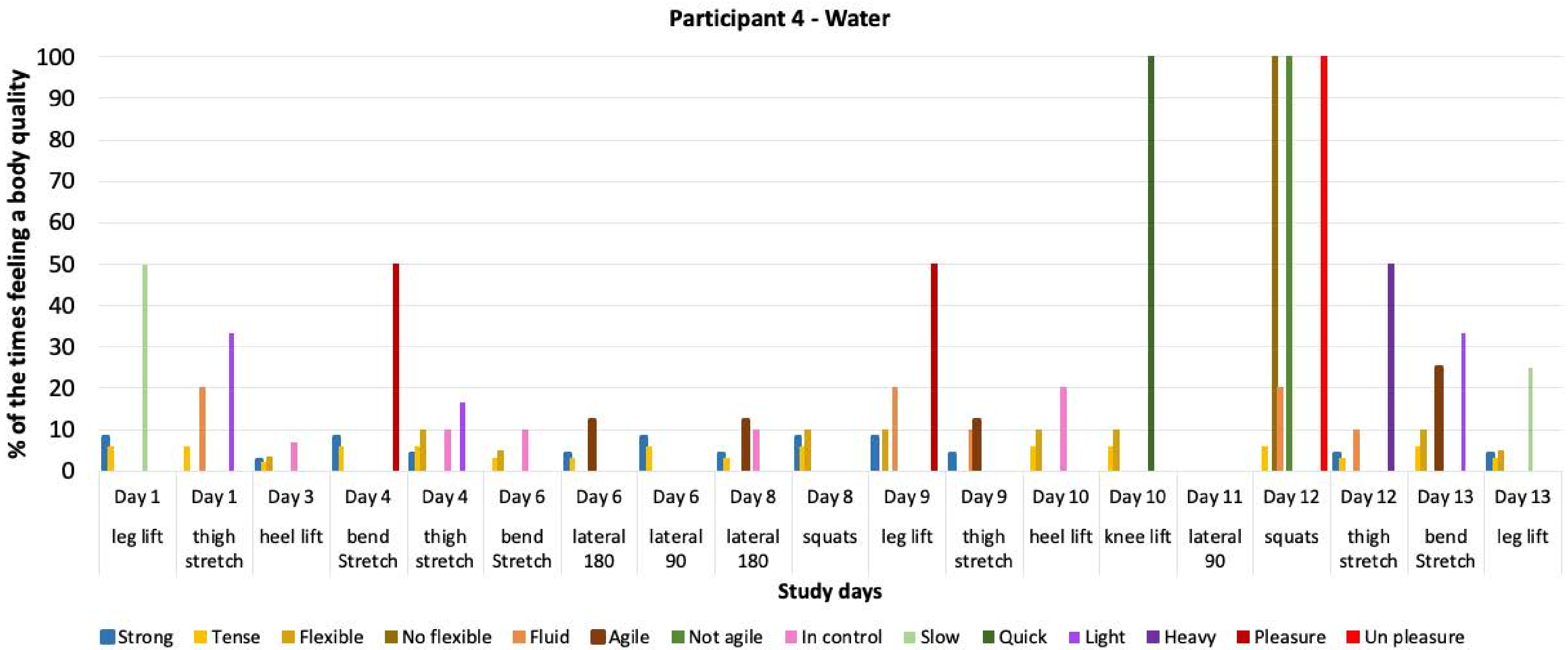

FIGURE 8.18: GRAPH SHOWING BODY SENSATIONS WITH THE WATER SOUND DURING THE HOME STUDY FOR PARTICIPANT P4.

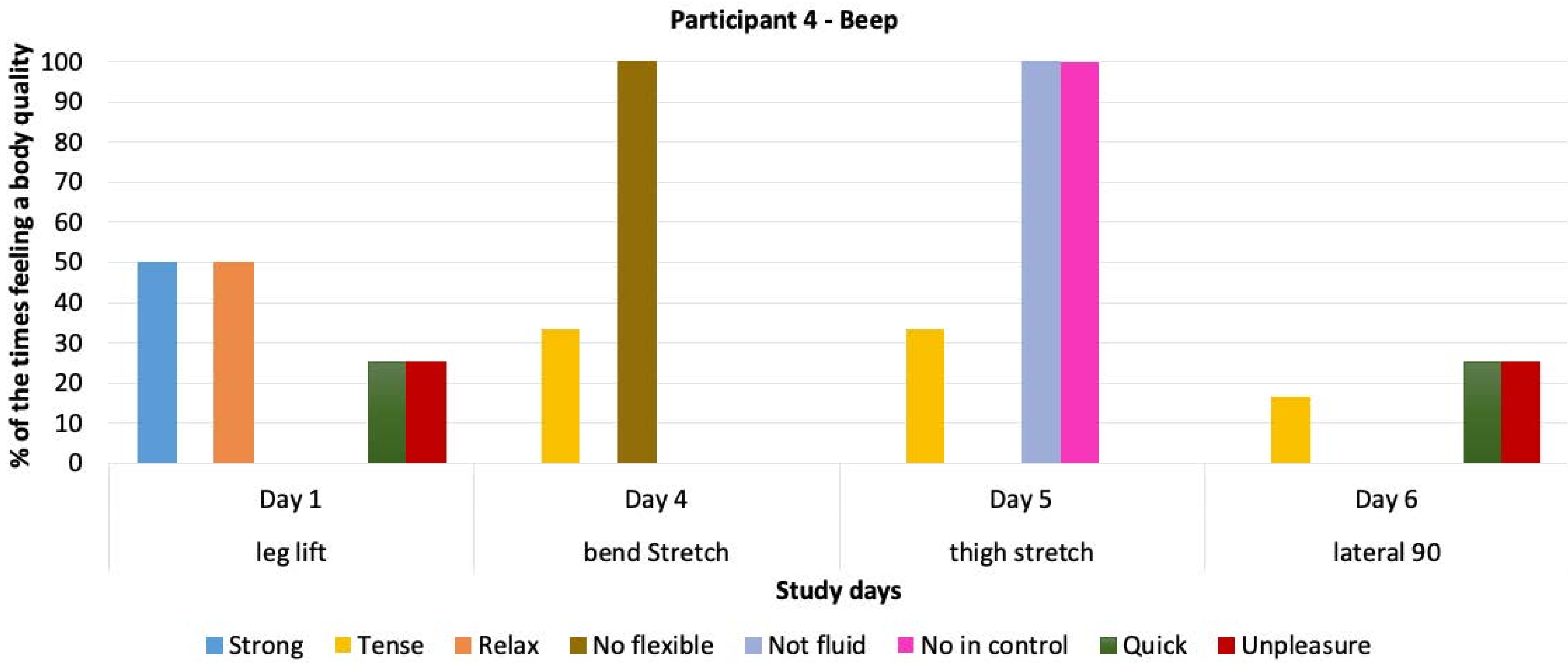

FIGURE 8.19: GRAPH SHOWING BODY SENSATIONS WITH THE BEEP SOUND DURING THE HOME STUDY FOR PARTICIPANT P4.

8.5.1.6. P5: profile and body sensations in the IP study

P5 is an office worker at the university. His daily routine consists of working at the university, transporting from home to the university and back, staying at home, walking with his dog, and spending time with his girlfriend, family, and friends. He does not have a routine of doing exercise recently.

He likes to go jogging, and he considers it is not necessary to do PA with someone else. However, the barriers that prevent him from performing PA are related to prioritizing other activities (e.g., work), lack of motivation, weather (e.g., "*The weather sometimes doesn't inspire me*"), and he doesn't feel fit. He gets very discouraged from playing sports because he stops and knowing that he won't play sports again for a while, he starts again, and he has already lost all the form he had gained. He doesn't feel worried about his body sensation when exercising "*because it's cool when after a session you feel that you've done it, that you've met your goals, and that you're tired and lying down, but you've done well, that's a good feeling*". His body sensations are tiredness and laziness.

In the beginning, P5 reported several body sensations with the "Wind" sound. It should be noted that the feeling of fluidity together with muscular tension, both were present for most of the exercises when these were performed with the sounds (FIGURE 8.20). On day 2, P5 reflected and reported feeling fluid, quick, strong, and satisfied during the "squat" movement. During the remaining days, with the "Wind" sound P5 felt strong (on day 4 with leg lift), not flexible (on day 4 with thigh stretch), and with a sense of pleasure on the last days (10, 11, and 12) (FIGURE 8.20).

For the "Mechanical" sound, on day 1, P5 felt relaxed and agile. In addition, on days 1 and 2, P5 felt strong and quick. P5 used the "Mechanical" sound from day 6 to 12, reporting to feel quick and pleasure on days 6,7, and 11. (FIGURE 8.21). Following this, with the "Water" sound, P5 felt a lack of flexibility on day 4, but felt quick on day 10, and pleasure on days 7 and 12 (FIGURE 8.22).

During the use of the "Beep" sound, P5 felt confused about two body sensations, as he reported both feeling agile and not agile on day 2. Also, the "Beep" sound seems to have affected his sense of fluidity on some days. But it seems to positively affect the "knee lift" exercise (FIGURE 8.23).

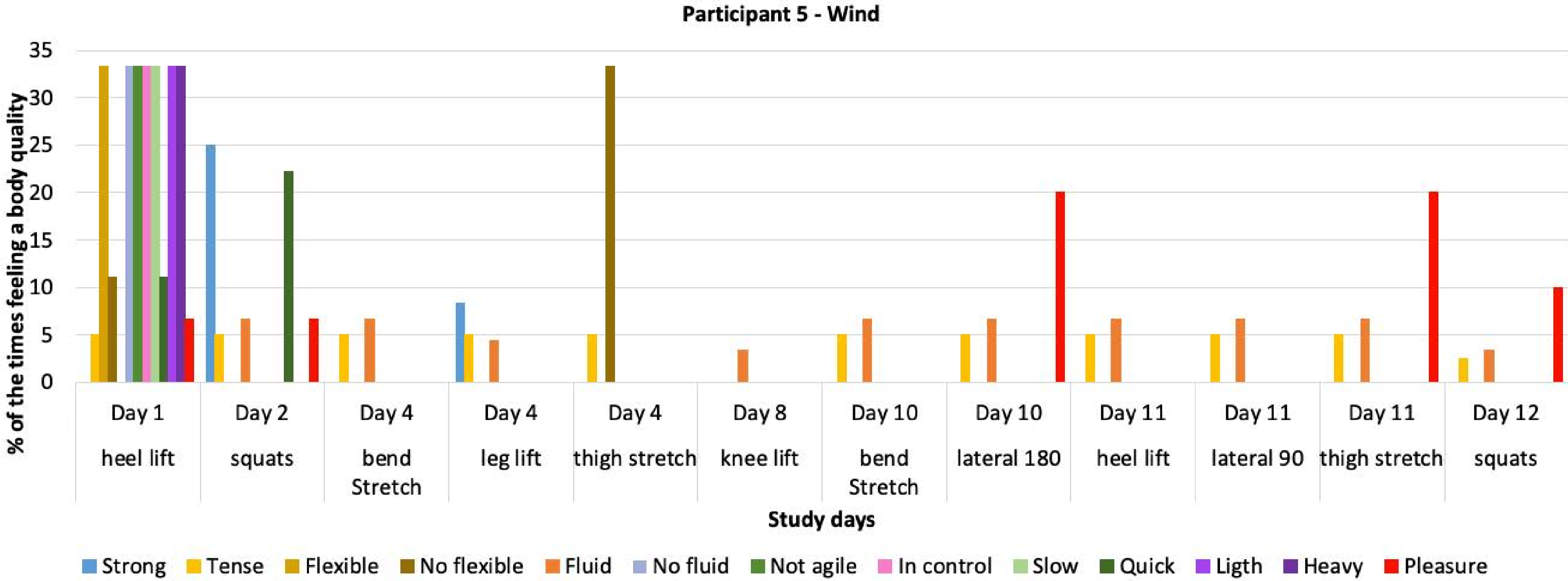

FIGURE 8.20: GRAPH SHOWING BODY SENSATIONS WITH THE WIND SOUND DURING THE HOME STUDY FOR PARTICIPANT P5.

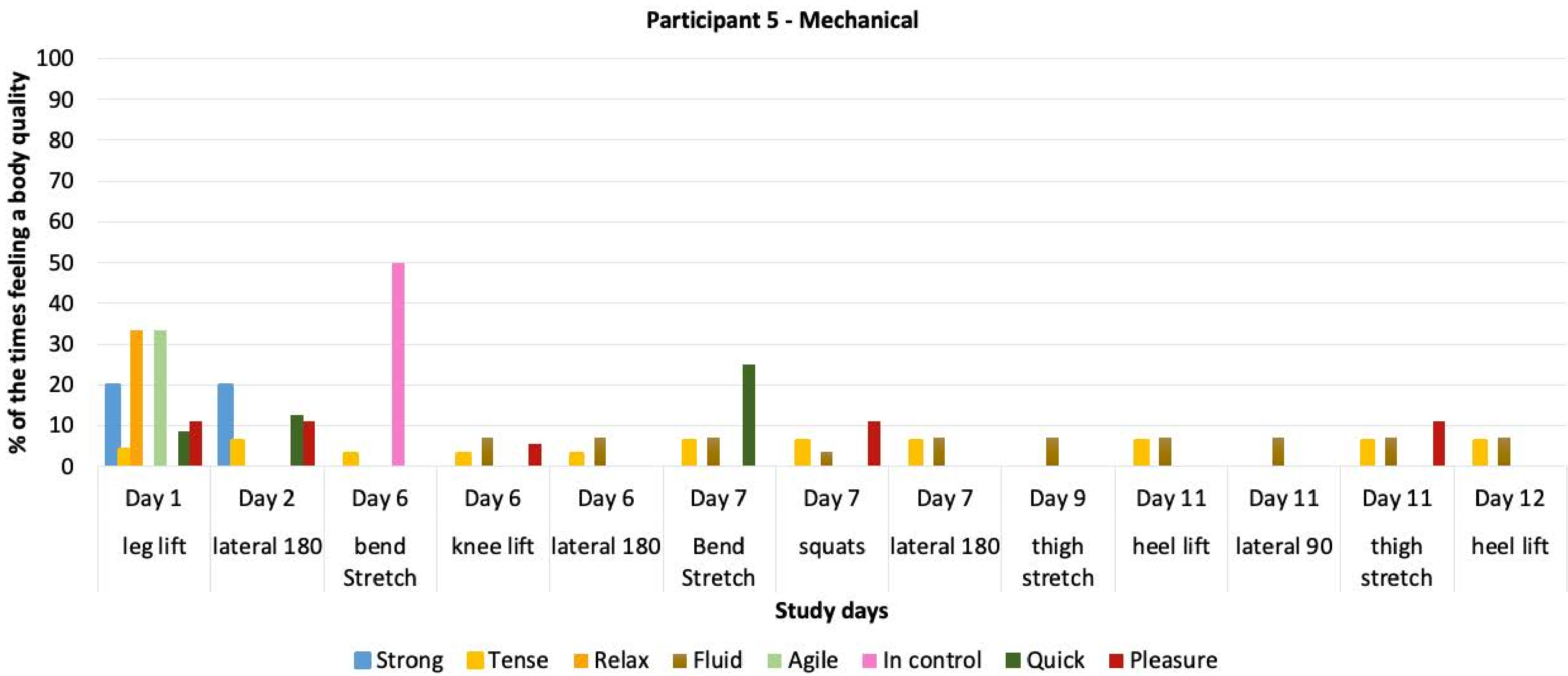

FIGURE 8.21: GRAPH SHOWING BODY SENSATIONS WITH THE MECHANICAL SOUND DURING THE HOME STUDY FOR PARTICIPANT P5.

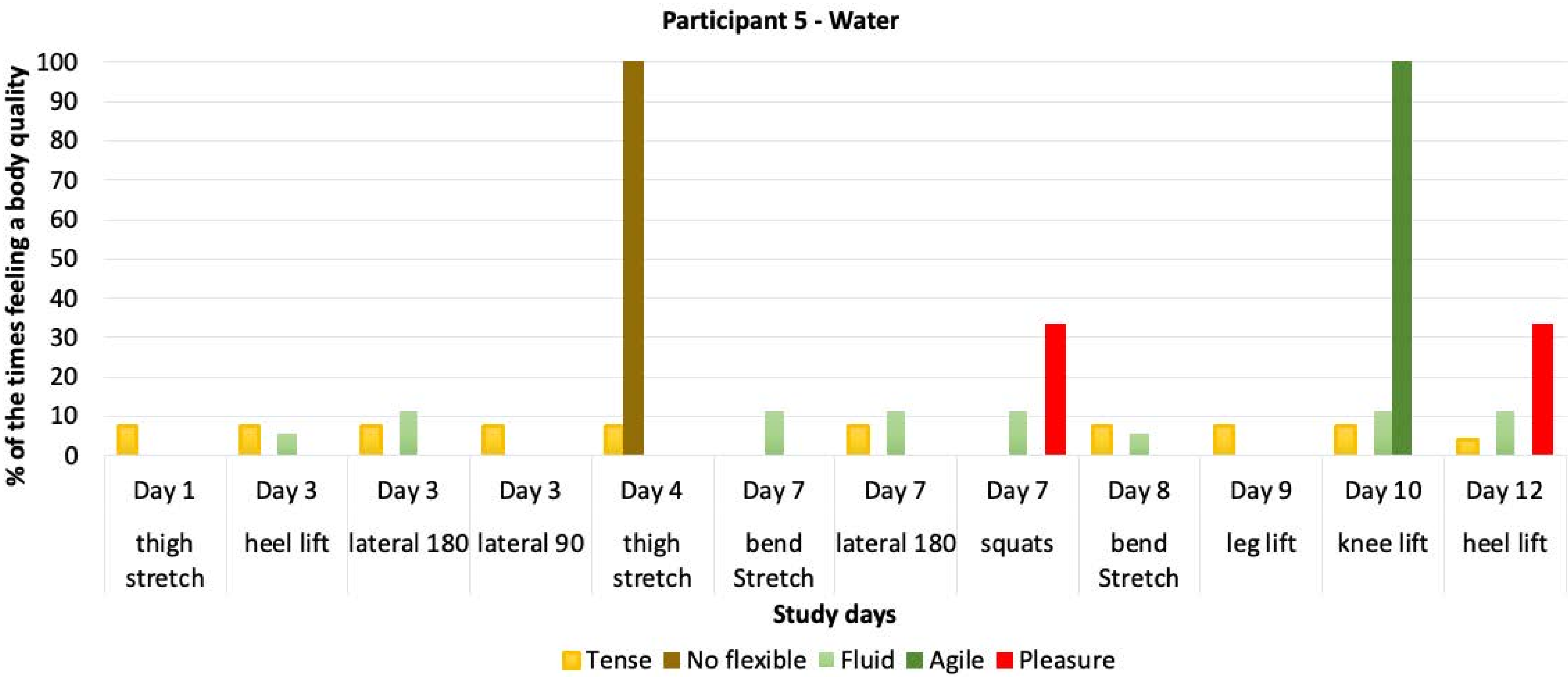

FIGURE 8.22: GRAPH SHOWING BODY SENSATIONS WITH THE WATER SOUND DURING THE HOME STUDY FOR PARTICIPANT P5.

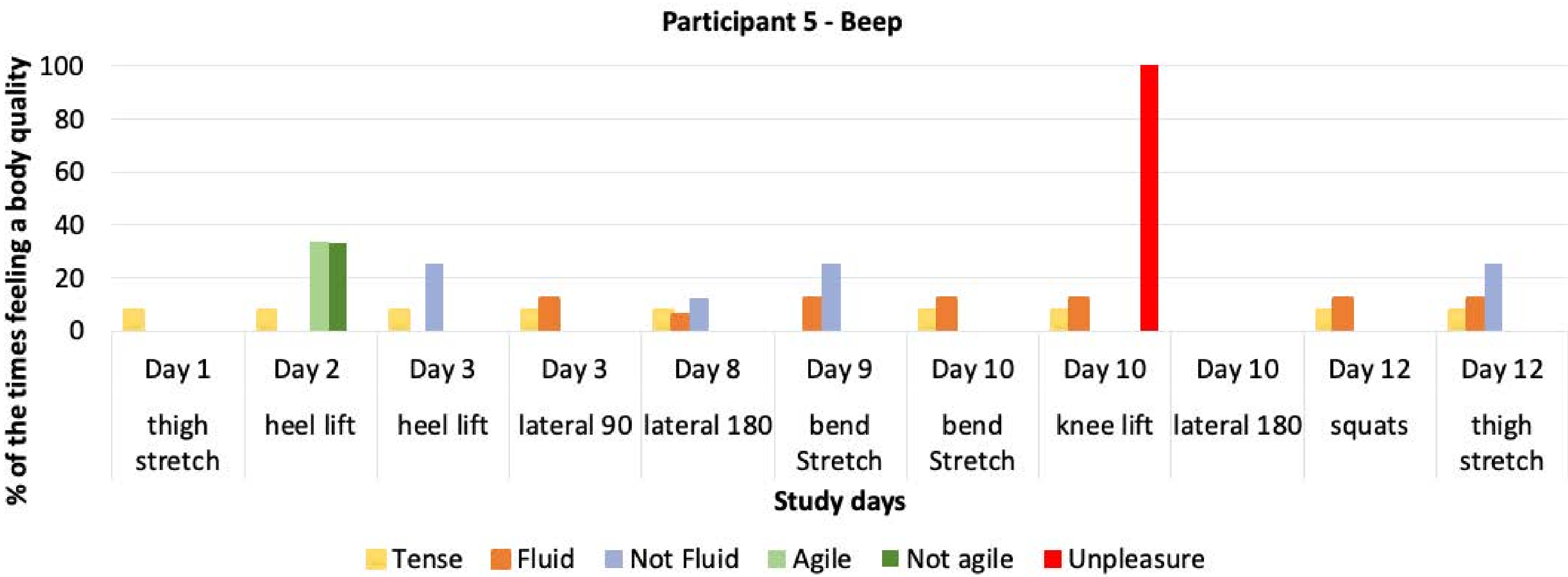

FIGURE 8.23: GRAPH SHOWING BODY SENSATIONS WITH THE BEEP SOUND DURING THE HOME STUDY FOR PARTICIPANT P5.

8.5.2. Impact on Body and Movement Perception

The sonifications affected the perception of the body/movement qualities that were presented to the participants in the Body Maps (e.g., strong/weak, flexible/stiff). Here the qualities that were perceived as being more impacted by specific sounds were discussed. See TABLE 8.8 which presents an overview of the effects on each quality, the summary was based on the number of the participants of each study that reported their body and movement sensations during their interviews.

TABLE 8.8: SUMMARY OF THE EFFECTS OF SPECIFIC SONIFICATIONS ON EACH QUALITY, DEPENDING ON THE STUDY.

Sound	**Study**	**Impacted Qualities**											
		Strength		**Control**		**Fluidity**		**Weight**		**Effort**		**Joy**	
		+	-	+	-	+	-	+	-	+	-	+	-
Mechanical	AP						X	X					X
	IP	X		X		X		X					X
Wind	AP			X		X			X			X	
	IP	X		X		X			X			X	
Water	AP	X			X		X				X	X	
	IP			X		X							X
Tone	AP					X			X			X	
Beep	IP		X			X			X				X

8.5.2.1. Impact on Perceived Strength

In the Wind sound condition, (n=4) most of the participants in the IP Study reported feeling stronger and perceived their movements as less effortful, noting a change in their emotional state: *"I felt strong with the Wind sound because I feel like it takes no effort to perform the movement. I felt the sound encouraged me up and helped me to hold my breath*." (P4-IP). This effect was also reported with the Mechanical sound (in most of the participants). One participant reported feeling less light in the forearm, because he felt he engaged more his upper arm muscles. This interplay between feeling light and required effort impacted his perceived strength: *"When you move this (forearm) it will feel like you are moving a (light) load; I liked the sound, so that's why (my arm) feels stronger, that is, it (the sound) motivated me to move, so (the upper arm) felt less light because it had more strength."* (P1-IP).

In the AP Study, the sonifications were perceived to impact strength only in few participants, who reported an impact of the Water sound and the Wind sound respectively on their perception of strength during squats. In both cases, this was closely related to the perceived movement effort: the Wind sound's frequency increased, and the Water sound played a splash in the squatting position (deemed by participants the most effortful point of the exercise), possible affecting their strength perception: *"Since the sound was quite heavy when I was down, it was feeling as if [I was] stronger, something in my muscles just by the fact that the sound was there"* (P4-AP).

8.5.2.2. Impact on Perceived Movement Control.

The Wind sound was perceived by most of the participants in both studies (n=5 in the AP Study, n=4 in the IP Study) to enhance the feeling of being in control of their own body and movement. In the AP study, participants attributed this to the perception that the Wind seemed to offer some resistance, as if they moved against it: *"I feel much more in control compared to without the sound. I have the feeling that I have some force back: when you push something, if there's nothing, it's easy to push it, but if there's something it gives you a push back"* (P3-AP). In the IP Study, participants attributed this to the feeling that they were controlling an external object, and this came together with an increase in the sense of agency: *"[it is] as if you were dominating it [the Wind]. As if you were releasing a balloon, that you are the one who makes that sound louder"* (P1-IP). **Frequency changes** of Wind allowed them to feel more in control, because: *"it (Wind) lets me know (about my movement), I moved with the sound, I started doing the exercise, I already reached the limit and I could go [further] down"* (P5-IP). About half of the participants also perceived this effect with the Mechanical and Water sounds. With Mechanical, the effect was attributed to the discrete feedback and metaphorical evocations: *"it seems that every time you make a small movement, as it sounds like a gear, it actually seems that you are turning something; so, it seems that you are really controlling the gear."* (P1-IP). With Water, it was attributed to **the splash feedback at the**

start/end position: *"My movements had more control because (I hear) the sound of the splash reflected me (to hold my position and control) when I lifted and lowered my leg."* (P4-IP)

In the AP study, the Water sound decreased in (n=3) some of the participants their sense of movement control, because it negatively impacted their sense of agency. A (n=2) few of them perceived that the Water sound added a dimension to their movement that did not match the exercises, e.g., the Water made them feel as if they moved also in the sagittal plane: *"I knew I had to go up and down but for some reason I started thinking about what was happening [in the sagittal plane]. It felt [like this] because it was like water, like being in a bowl, going from one side to the other. […] It doesn't reflect my movement. I didn't feel in control".*

8.5.2.3. Impact on Perceived Movement Fluidity

In both studies, participants related fluidity to how they perceived their movement to be in relation to pace and their coordination. The Wind sound positively impacted the perception of movement fluidity in both studies (all the participants in the AP Study; n=3 participants in the IP Study). In both studies, this was attributed to a well-supported sense of agency, e.g.: *"I think the fluid sensation of the perception is also coming from the synchronization between the movement and the sound"* (P3-AP). In addition, participants in the AP Study attributed it to the **characteristics of the sound** (i.e., *"ongoing and continuous" P7, "very gradual" P6)* and how it evoked the real wind: *"it becomes a little bit more fluid [because] you really relate to the wind; it goes and comes"* (P1-AP). Participants in the IP Study attributed it to **gradual changes** in frequency and intensity, the perceived **pace** and **continuous** feedback and pace: *"when you move slowly it sounds a little less fierce, when you move faster or are reaching the top, it sounds much louder, that is why you feel that it sets the pace better because it is sounding different throughout the movement"* (P1-IP).

The Tone and Beep sounds also supported the feelings of fluidity. (n=5) Many participants in the AP Study said that it reminded them of other fluid movements, e.g.: *"when I heard the sound I thought, first of all of a ball, because of the bouncing. It felt like quite a fluid thing, something that I would like to do"* (P7-AP). In the IP Study, a participant related it to the ease of exercise: *"I think my movements were quite coordinated and fluid because this exercise seems easier to me [with Beep]."* (P2-IP).

The Mechanical sound elicited opposite effects between the two studies. It positively impacted fluidity in (n=2) some of participants of the IP Study, because it supported well their coordination and pace with the sound (e.g., *"the sound accompanied me"* or *"[the sound is] marking you [your movements] at all time"* [P1-IP], even though the sound was discrete. In the AP Study, all the participants felt their movement to be less fluid and stiffer, which was attributed to unpleasant metaphorical associations: *"it definitely [negatively] affects the fluid aspect of it [...] I don't picture my movements to be like [imitating cranky sound of the mechanical] like a machine [...] that needs some kind of fixing"* (P1-AP).

Finally, the Water sound also elicited opposite effects between the two studies. In the IP Study it made (n=3) most of the participants feel flexible. This was attributed to metaphorical associations to real water: *"I selected fluid, agile, in control, and light, because as I tell you, close your eyes and it is like being in water, to a certain point, it (the sound) is quite credible."* (P3-IP). In the AP Study, the fact that the Water presented an after-movement effect with the splash negatively impacted the participants' fluidity perception: *"I felt I had to wait for the sound [...] I felt less fluid, for sure"* (P2-AP).

8.5.2.4. Impact on Perceived Weight

The Wind sound made most of the participants in both studies perceive their body as lighter (n=4 in the AP Study, n=3 in the IP Study). In both studies, participants attributed it to connotations of lightness and its metaphorical associations, e.g.: *"you look more like a bird and you're fapping."* (P2-IP). In addition, in the IP Study it was also attributed to the high pitch of the sound in the end position of a movement: *"the "pitch" of the sound helps me keep my arm up. I felt flexible with Wind and also my body felt lighter and faster."* (P4-IP).

The Mechanical sound had the opposite effect in both studies (n=4 in the AP Study, n=3 in the IP Study), making most of the participants feel heavier. They attributed it to metaphorical associations to machinery, chains, which are heavy objects: *"I wouldn't feel light, because of the sound associated is heavy"* (P3-AP). For participants in the IP Study, this added a sense of tiredness *"I feel that my body is much heavier, and it tires me more."* (P4-IP).

The Tone sound made (n=5) most of the participants in the AP Study feel lighter because it *"makes me feel like it was a spring"*. It made them think of jumping, as if they were light. The Beep and Water sounds made (n=3) most of the participants in the IP Study feel slightly lighter, due to negative metaphorical associations (e.g., to hospital machines beeping), desiring to finish the exercise faster, and therefore increase their movement pace although they did not articulate how these effects came to be.

8.5.2.5. Impact on Perceived Movement Effort

The sonifications impacted the sense of effort only in the IP Study. In the AP Study, it was not a quality generally perceived to be affected, which may be attributed to the participants being physically active and hence to a reduced level of challenge and need for support in performing the exercise.

In the IP Study, the Water sound, and in particular the "Underwater" part of the sound, decreased the participants' feelings of effort and increased those of relaxation, due to associations with being in real water: *"I like it because it is less work, when you are in the water or sitting on the edge (of the pool) with your legs doing the movement with your foot"* (P2-IP). Participants also reported that it allowed them to distract themselves from the exercise: *"The sound of water ... allowed me to focus on the water and evade my mind from exercise"* (P1-IP). Yet, some participants could perceive effort if they imagined the water resistance: *"I felt like I was trying harder. It helps me imagine that I am exercising in the water and offers resistance. By imagining the resistance of the water, I think I try harder."* (P4-IP). This was well received: *"It's not like it is more effortful to do the movement, rather, I noticed that I was trying harder (to) do [it]"* (P4-IP). The Wind and the Mechanical sounds positively impacted the sense of effort because they were perceived as being well semantically synchronized, e.g.: *"the sound that I liked for this (bend and stretch) exercise is Wind; the reason is that it goes according to my effort. It is intense when I make more effort and it decreases when I reduce effort."* (P5-IP).

8.5.2.6. Impact on Movement Joy/Pleasure

Moving with the Wind sound was enjoyable for (n=7) all the participants in the AP Study, and (n=3) most participants in the IP Study. This was attributed by participants to the sound being **personally rewarding** and offering *"an enjoyable experience"* (P4-AP). Participants in the IP Study found that there was a sense of pleasure even when the exercise was hard, due to a **well-supported sense of agency**: *"I am quite satisfied with this sound [...], because it seems that I can control the intensity of the air."* (P1-IP).

The Mechanical sound elicited the opposite feelings in both studies, due to unpleasant metaphorical associations to e.g., rusty machinery, broken bones, chains: *"you look like a broken toy, it's okay, but it's a bit annoying"* (P3-IP). Some participants also reflected that they *"did not want this sound associated with my movement"* (P1-IP).

The "Water" sound was well received in the IP Study, and (n=5) all the participants reported feeling pleasure. This was attributed to how the sound elicited feelings of comfort, of relaxation, and of being capable of performing the exercise: "*the relaxation that the "Water" causes me makes me feel more agile, more predisposed to do the exercise, and with more capacity to do [them]"* (P3-IP). In the AP Study, since it was perceived to not support the sense of agency well, participants found that while the sound was pleasing, its use in those exercises was not, due to the lateral dimension to the movement that it added: *"I enjoyed the "Water", it was a nice sound, but not for [squats]"* (P7-AP).

Doing movements with the Tone sound was reported as pleasurable in the AP Study by (n=7) all the participants because it was perceived as playful: "it was pleasing, because it was kind of funny" (P3-AP). However, doing movements with the Beep sound in the IP Study was reported as rather unpleasant by (n=5) all participants, mostly due to this sonification not supporting the sense of agency well, especially when it was not well calibrated: *"I was confused by the Beep sound, I also felt that I was uncoordinated"* (P2-IP). Still, with a proper calibration, most of the participants perceived that the sound made them hurry up, which they found annoying: *"(it is like) an alarm clock [...] gives me a sense of urgency, [...] and on top, it's annoying"* (P1-IP).

8.5.3. Impact on the Physical Activity (PA)

The sonifications also affected the PA of the participants. This section present aspects of the PA that were perceived as being more impacted by specific sounds, and which relate to movement pace, movement structure, and movement endurance. TABLE 8.9 presents an overview of the effects of sonifications on PA, the summary was based on the number of the participants of each study that reported their changes on PA during their interviews.

TABLE 8.9: SUMMARY OF THE EFFECTS OF SPECIFIC SONIFICATIONS ON PA, DEPENDING ON THE STUDY.

Sound	Study	Movement Pace				Movement Structure			Motivation		
		Increase Awareness	**Gauge & rhythm**	**Follow rhythm**	**Slow down**	**Awareness start/end**	**Awareness trajectory**	**Guide movement**	**Finish reps**	**Do more reps**	**Push boundaries**
Mechanical	AP			X		X	X				X
	IP			X		X	X				X
Wind	AP	X	X	X		X	X	X	X	X	
	IP	X	X	X		X	X	X	X		
Water	AP	X	X	X	X						
	IP	X	X		X					X	
Tone	AP			X		X			X	X	
Beep	IP					X					

8.5.3.1. Impact on Movement Pace

Sounds that were playing throughout the whole movement (start/end and movement trajectory), and featured gradual changes (in e.g., frequency, intensity, or timbre) between the two calibrated positions gave participants an **increased awareness of movement pace** (n=3 some participants in AP Study; and n=7 all participants in the IP Study), as the sound changed according to it. The "Water" and "Wind" sounds fostered this effect: *"I was definitely more able to see how fast or slow my movement was"* (P4-AP). Participants in both studies also made use of the sound characteristics above to **gauge and adapt the pace of their movement**, e.g.: *"I could use [the sound] to gauge the duration of how long I was staying in the squat […] I could kind of keep that same duration every time"* (P1-IP).

The repetitive nature of the exercises (multiple repetitions) emphasized the cyclic nature of sounds that played without stopping throughout the movement, such as Wind and Mechanical. Some participants (n=3 from the AP and the IP Study) in both studies said that this allowed them to create and follow a rhythm, e.g.: *"As [Wind] is a continuous sound, you felt like you keep it going. [...] it's a sound that doesn't stop basically, it has [...] a repetition"* (P3-AP); similar comments were made for the Mechanical sound in IP Study. In the AP Study, this effect was also supported by sounds with changes in the two extremes, e.g., with "Tone" and "Water", knowing what changes in the sound to expect enabled participants to keep a rhythm: *"Even though [the sound] wasn't continuous, like the "Wind", I could have the expectation of when the splash would come, which makes the melody build in my head"* (P6-AP).

8.5.3.2. Impact of Sound structures on Movement characteristics and perception

Discrete sounds marking the start/end of the movement through gradual changes between the two calibrations, reaching their minimum and maximum at those points (such as Mechanical and Wind sounds), gave some of the participants (n=3 in AP Study, n=2 in IP Study) in both studies an **increased awareness of the start and end of movement** (see TABLE 8.9): *"whenever I got the sound at the end, I knew that [I'm at the end]. [...] It means I've gotten to that point that I said in calibrations"* (P5-AP). Sounds that only played at the start or end of the movement, such as Beep and Tone, also fostered this effect. Some participants used this effect to **gauge their movement**: *"What I did at the beginning was: where is my benchmark? Where is the maximum [squat] that I can do? [...] It's like a way of measuring where I should go*" (P1-AP). Other participants used it as a guide, to know when to resume their movement:

"[I] go down and when [I] hear that [I'm] done, come back for the next one" (P5-IP).

Finally, sounds that played during the **movement trajectory** (such as Wind and Mechanical) gave participants an increased awareness of the movement trajectory (n=4, most participants in AP Study, n=2, a few in IP Study). With the Mechanical sound (discrete sound), participants could associate one of the discrete 'ticks' to a position in the movement: *"this sound has a clear cut [tick sound], and somehow it gives me a clear sense of the state of my movement, so I can [map it] to my movement [...] I'm more aware of each stage of the movement*" (P3-AP). A continuous sound such as Wind furthered this effect, guiding participants throughout the movement, as captured by this quote: *"[the sound] guides. I understand the relationship is that the body movement goes first and then comes the audio, but somehow, they're so much in synch that for your mind, it feels like the audio is helping you guide your movement"* (P2-AP).

8.5.3.3. Impact on Movement Endurance

Sonifications that were perceived to be personally rewarding enhanced the participants' endurance when doing the exercise, making nearly all of them **finish the set of repetitions** they had set for themselves (n=4 in AP Study, n=4 in IP Study), e.g.: *"[Water] and [Wind], they are the ones I feel most comfortable doing the exercises with, and the ones that motivate me the most to keep doing the exercise"* (P4-IP). Personally rewarding sounds showed potential to make participants do more repetitions than what they initially planned on doing: *"[Water] motivated me to hit more, to continue (doing the movement) [...] I didn't feel heavy at all, I could kick more, I said maybe I have to do 10 more, then I do 10 more."* (P1-IP).

The Mechanical sound, discrete and playing throughout the movement and presenting changes in frequency and speed, encouraged few participants (n=1 in AP Study, n=2 in IP Study) in both studies to push their boundaries. This occurred because once the maximum calibration had been reached, the sound did not stop, but continued playing, inviting the participants to pursue the movement. As the frequency increased throughout the movement trajectory, once participants had reached the maximum calibrated position, they had the expectation that the sound would continue to increase in frequency if they pushed the boundaries of the calibration (e.g., reach lower in the squat): *"pi-pi-pi" sounds, it motivates you more to continue until you see where the "pi" ends, because you think the "pi" will continue"* (P1-IP).

8.6. Discussion

This section discuss similarities and differences in the reported effects of the metaphorical qualities on BP in light to prior work.

8.6.1. Similarities Between Populations

The results showed similarities in how participants from both populations perceived that the movement sonifications (particular characteristics and metaphorical qualities) affected their own BP and PA.

The Wind sound was arguably the most successful one. It elicited positive metaphorical qualities for both populations, such as being gently pushed by it; and positively impacted their perceptions of **control** of their own body, **fluidity**, **weight,** and **joy of movement** [126], [187]. It supported participants in PA by increasing their **movement pace awareness**, **gauging their**

pace and **follow a rhythm**. It also supported them in becoming more aware of their **movement start/end and trajectory**, and it offered them a guide on the movement. Several participants said that it enabled them to **finish the set of repetitions** during the exercise. These manifold positive effects are bound to several factors: the sound supported well the participants' sense of agency, it was personally rewarding, and participants found a response to their movement and effort that it enabled positive metaphorical qualities (to wind itself, to flying, to nature) and its particular characteristics (continuous, sounding throughout the movement with changes in frequency and intensity) were perceived to offer support during PA.

The Mechanical sound negatively affected the perceived **weight** and **sense of joy**, due to negative metaphorical qualities that made participants perceive their body as a "heavy object", machinery or rusty chains. Yet, it enabled positive BPs and effects in both populations, such as encouraging participants to **push their movement boundaries**, because of its sound characteristics (discrete, sounding throughout the movement and presenting changes in frequency). This effect aligns with prior research results on the use of discrete sonifications [25], [27], [41]. The results extend those with additional effects of this type of sound, such as increasing awareness of **movement start/end and trajectory**.

In both studies, the two tonal sounds, Tone and Beep, positively impacted **flexibility** and **weight**. For the Tone, these effects were mostly due to the positive metaphorical qualities that the sound elicited (e.g., "pulling the body"). For the Beep, it was the opposite: negative metaphorical qualities (e.g., to hospital machines beeping) made participants increase their movement pace, as they reportedly desired to finish the exercise faster. Yet, this increase in pace made them in turn feel more flexible and less heavy. These sounds enabled participants to become aware of their movement start and end, which is related to their sound characteristics (only playing at the calibrated start/end), which aligns with prior research [22], [25].

8.6.2. Differences Between Populations

Importantly, the results surfaced positive effects of the metaphorical qualities on PA and BP in the inactive population that were not present in the active one.

The effects on the perception of **effort** and **strength** were affected in the IP study, but not in the AP study. This could be attributed to the fact that for the physically active participants, the AP study set-up (i.e., performing few repetitions with each sound) did not last enough to allow them to experience an effortful workout – as they were all used to train in substantially more strenuous activities in their everyday life, as reflected in the results of the IPAQ. Their baseline physical fitness and strength potentially prevented them to perceive any effect from the sonifications in that regard, as it has in the physically inactive people. In terms of PA, the physically inactive participants reportedly engaged in more PA during the IP study duration than in their everyday life, and some sonifications encouraged them to increase their movement endurance (e.g., finish the repetitions); as such, their effort increased. Moreover, some- times when they performed the movement, they were focused on the sounds, about what sonifications evoke or how the sonification characteristics reflect their effort; as such, sonification helped to evade the mind of the exercise. Therefore, the sonifications lowered their perceived effort and increased their perceived strength.

The "Water" sound affected positively **movement control** and **fluidity** in the IP study, but not in the AP study. This could be attributed to differences in physical skills. The "Water" after-effect (lingering splash sound) was perceived by both populations to slow down their pace. For the physically inactive participants, slowing down together with positive metaphorical qualities associated with nature and bodies of water (as reported in the interviews), which enabled the perception of being immersed in real water. A previous study (Singh et al., 2016) mentioned how water evokes on participants spontaneously swimming movements; this is linked to specific exercises in this work (e.g., "side arm raise"). This, in turn, extends how in both studies the "Water" sound made participants feel more relaxed and comfortable with the movement, and distracted them from the exercise. It is contended that this may have supported well the perception of being in control of their own body and movement, as well as of moving with fluid movements. Yet, for the physically active participants, the slowing down prevented them from keeping their normal pace (i.e., they felt forced to wait for the sound to pass before resuming the exercise). Some participants reported that they perceived metaphorical qualities that were not consider during design, such as "Water" adding a lateral dimension to their movement (i.e., they perceived a lateral movement in exercises that mostly featured upwards/downwards movements, such a s squats). While most participants deemed it a negative perception, it could be interesting to explore further this novel effect on the movement space, in exercises that can leverage it positively.

The Mechanical sound positively affected the feelings of movement **fluidity** and **coordination** in the IP Study, but not in the AP study. This is attributed to differences in physical skill and movement awareness. For both populations, the sound elicited negative metaphorical qualities that were not consider during design, such as thinking of their body as a cranky machinery, or breaking limbs – which was enough for the active participants to report their movement as less fluid. For the inactive population, however, participants perceived specific sound characteristics (discrete, sounding throughout the movement with gradual changes in intensity and frequency), to positively impact their proprioception during the exercise, which in turn made them feel more coordinated, and fluid [25], [41], [108]**.** This might be due to people with low PA confidence needing to know where their body is due to fear of pain or poor balance [41], and that acknowledgment of what they are doing can build confidence. Instead, more capable people may focus on their beauty or grace of their movements, and the chosen feedback needs to reflect that.

8.7. Conclusion

This chapter has explored the impact of different metaphorical sonifications on BP and PA for two populations: one with physically active participants over multiple days and one with physically inactive participants at their homes using the system during two weeks. Through two qualitative studies have identified several effects enabled by five different metaphorical sounds present in the wearable device SoniBand. These contribute to the body of work on sensory feedback, and in particular movement sonification [17], [25], [27], [33], [187] to alter BP. The novelty of these studies lies in the use of metaphorical sonifications to address negative/distorted BPs in different contexts: inside and outside of the laboratory.

This chapter also presents a methodological contribution regarding the use of Body Maps. The Contextual Body Map departs from previous depictions [31], [210], [214]–[216] in that it contextualizes the silhouette in a particular movement exercise, which participants in the AP Study said it enabled them to better ground particular perceptions and feelings to specific body parts or exercise phases. Previous works have employed Body Maps as a sensitizing and individual reflection tool for the participants or designers and researchers (e.g., [210], [215],

[216]), rather than an active method to mediate interviews. Our work extends these current uses through having employed them to facilitate reflection, to obtain at the same time the participants' impressions in a researchable format.

However, one of the limitations is that both studies conducted have centered on specific strength and flexibility exercises, which worked well with SoniBand's metaphorical sonifications. Several of the perceived effects are underpinned by the cyclic nature of the exercises. Moreover, the qualitative studies did not look for impact on adherence or quantitative changes in PA. Therefore, future work is needed to explore the sonifications' potential in other types of PA and contexts of use (e.g., outdoors PA), to understand the technology adoption and the potential effects on PA adherence. For instance, interesting future research directions could be to study the effects of these metaphorical qualities and sound characteristics on longer exposure studies and evaluate long-term adherence to PA in real-life contexts, in order to support people that are physically inactive. Also, to further explore and map sound characteristics and metaphorical qualities to address barriers related to negative self-BP.

Finally, unlike previous studies addressing negative BPs, which have been quantitative and carried out in the form of controlled laboratory studies (Chapter 7). This chapter adopted a qualitative approach, involving two different populations and contexts, interviews, and body maps to ground the participant's reflection on the sonifications' effect on body/movement perception and on the PA.

8.8. Chapter summary

This chapter selected SoniBand and the movement sound palette to work on the understanding of the characteristics and capabilities of the metaphorical movement sonifications to affect people's perception of their body capabilities. First, this chapter proposed two qualitative studies with different populations to perform strength and flexibility exercises. One study with physical active participants in their workplace and a second one with physical inactive participants that perform the study in their home. Both studies that center on addressing an identified group of critical psychological barriers to PA: negative or distorted body perceptions (e.g., feeling incapable or weak to perform PA).

The results showed that SoniBand's metaphorical sonifications elicited similar positive effects in both populations, such as increasing the sense of movement fluidity and of being in control of their own body movement when exercising; and increasing their movement endurance. At the same time, it also highlighted differences in how the characteristics of the sounds affected both populations, for instance in terms of perceived effort and strength.

In the next chapter, this thesis presents the discussion and conclusion of this thesis for supporting PA based on the psychological barriers related to BP.

9. DISCUSSION

This chapter presents a summary of the main results of this research work. In this work, a series of strategies were proposed to design movement-sound palettes for PA in physically inactive adults. Three quantitative studies and two qualitative studies are reported for which a series of sonifications were designed for exercise programs such as walking, stretching, and strength. In past works, movement sonification has been mainly used to support rehabilitation, sport, or dance. Little research has been done on overcoming, through sound, psychological barriers that prevent them to engage in PA, in particular those barriers related to BP (as in [68]), i.e., how people perceive their own body and capabilities. Rather than just working on PA monitoring or increasing motivation with goals or rewards, this thesis work proposed the use of metaphorical sounds (e.g., water), and in particular the use of sonifications that exploit the properties of such metaphors to evoke different body sensations (e.g., fluidity), help body awareness, generate positive perceptions and/or enhance the perceived physical capabilities. These changes in BP may in turn increase the motivation for PA and facilitate adherence to PA in people's lives, which is a challenge or it is perceived as demanding by people with a low level of PA.

9.1. Quantitative studies

The main results of the quantitative studies carried out in this research work can be observed in TABLE 9.1.

In the first controlled study, for the "walk" exercise, one of the more significant findings that emerged from the study is that the "Wind" sound made physically inactive participants feel less tired during PA. The "Wind" sonification at the same time elicited the sensations of being in control over the movement, feeling excited, and with a heart/breath more accelerated. These effects could suggest an increase of the perceived movement effort, i.e., the strength applied. Although the "Wind" sound made people feel comfortable during their movement, it seems that the increase in perceived effort also made people feel less happy. Nevertheless, this reduction in the feeling of happiness seems not to interfere with other positive body sensations, like being in control of one's own movements. Future works are needed to confirm whether the potential of the "Wind" sound to evoke the perception of effort is related to a reduction in positive feelings. These results, about "Wind". are complemented by other quantitative (e.g., in "thigh stretch" and "leg lift" exercise) and qualitative findings with design considerations. It should be noted that in previous studies it was reported that the "Wind" sound evoked a sense of happiness and joy in children [112].

In the case of the "Can-crush" sound, there was a sense of more flexibility and a change in movement pattern, where participants spent less time in contact with the ground which may mean participants were more activated during walking. These effects differ from those observed for its control sound, which made participants spend more time in contact with the ground and it evoked the senses of heaviness and tiredness, which relates to the findings in [17], [33]. For example, in [33] the participants used a gym step or were asked to climb stairs while listening to modified versions of their footsteps (low or high frequency versions). Results showed a lower frequency effect in greater contact time with the ground during gait and in participants reports of feeling heavier. Although these results evidence the effects of sonifications during the walking movement, in the case of the "Can-crush" sound, further research is needed to understand the link between the sound and the sense of flexibility and the reason why participants seemed to be more active as measured by the reduction in the time their feet were in contact with the ground.

Furthermore, in the first controlled study, for the "thigh stretch" exercise, it was observed different effects for the three main sounds: "Mechanical", "Water", and "Wind". The "Mechanical" sound elicited the sensations of heaviness, tiredness, muscles working harder, better proprioception, and it also elicited changes in movement behavior, as participants spent more time in the downward movement, i.e., leg going down slowly. In the case of the "Water" sound, the body sensations present were flexibility, lightness, speed, agility, fluidity, less tiredness, and exercise ease. There were also effects of the "Water" sound in emotional state, as this sound increased motivation, happiness, and comfort, and in movement behavior, as this sound increased the upwards deceleration and the downwards acceleration of the "thigh stretch". Lastly, the "Wind" sound made participants feel less tired, as well as more agile, with more fluid movements and finding the exercise easier. The "Wind" sound, in the case of "thigh stretch", also had an effect on the emotional state, making participants feel more comfortable, more motivated, and happier. Given that in this scenario the sounds and movement seem to work well to generate changes in body feelings, emotional state and movement behavior, the question remains as to how the characteristics of movement and sound link and interact with each other to evoke positive BPs and changes in behavior [17], [25], [41].

TABLE 9.1: SCHEMATIC SUMMARY OF RESULTS ON THE EFFECTS ACROSS ALL THE EXPERIMENTS. IN THE SIDE ARM RAISE EXPERIMENT, ONLY THE EFFECTS OF UP/DOWN SOUNDS ARE SHOWN; FOR MORE DETAILS OF OTHER EFFECTS AND CHARACTERISTICS OF CHANGING PITCH SOUNDS SEE TABLE 7.12.

			Walk		**Thigh stretch**			**Leg lift**			**Side arm raise**
Dimension		**Predicted effects**	**Wind**	**Can- crush**	**Mechanical**	**Water**	**Wind**	**Water**	**Up**	**Wind**	**Up/down**
Bodily movement		Dec/acceleration/ velocity	n/a	n/a	n/a	✓	n/a	n/a	n/a	n/a	✓
		Time	✗	✓	✓	✓	✗	✓	✗	✓	✗
Proprioceptive awareness		Accuracy of final position	n/a	n/a	n/a	n/a	n/a	✓	✗	✓	✗
		Proprioception	✗	✗	✓	✗	✗	✗	✓	✗	✓
Bodily and emotional feelings	Feelings about the body	Strength	✗	✗	✗	✗	✗	✓	✓	✓	✗
		Speed	✗	✗	✗	✓	✗	✗	✗	✗	✓
		Agility	✗	✗	✗	✓	✓	✓	✓	✓	✗
		Building muscles	✗	✗	✓	✗	✗	✓	✗	✗	✗
		Weight	✗	✗	✓	✗	✗	✓	✓	✓	✓
		Tiredness	✓	✗	✓	✓	✓	n/a	n/a	n/a	✓
		Heart/Breath accelerated	✓	✗	✗	✗	✗	n/a	n/a	n/a	✗
		Flexibility	✗	✓	✗	✓	✗	n/a	n/a	n/a	✗
	Feelings about the movement	Sense of control	✓	✗	✗	✗	✗	n/a	n/a	n/a	✓
		Difficulty	✗	✗	✗	✗	✓	✓	✓	✗	✓
		Comfort	✓	✗	✗	✓	✓	✗	✗	✗	✓

		Capability	✗	✗	✗	✗	✗	✓	✓	✓	✓
		Coordination	✗	✗	✗	✗	✗	✗	✗	✗	✓
		Fluidity	✗	✗	✗	✓	✓	✓	✗	✓	✗
	Emotional feelings	Motivation	✗	✗	✗	✓	✓	✓	✓	✓	✓
		Happiness	✓	✗	✗	✓	✓	n/a	n/a	n/a	✓
		Arousal	✓	✗	✗	✗	✗	n/a	n/a	n/a	n/a

The “walk” and “thigh stretch” study allowed in this thesis to test the proposed approach that exploits bottom-up mechanisms identified in neuroscientific studies, where sensory feedback allows changing BP [14], [105], and uses movement sonification to address barriers to PA related to BP. The proposed approach aligns with works on sensorimotor transformations showing how sensory feedback on movement implicitly biases behavior [25], [37]. This work extends previous studies showing that real-time sound feedback on one’s body can alter BP, change emotional state and behavior [17], [25]. While these previous studies have worked with altering naturally produced sounds, this thesis used sonifications that evoke body sensations at a metaphorical level for altering BP. Previous works with sonification have shown how through sound feedback it is possible to lead movement or give information about it from start to end [21], [41]. They have discussed the possibility of using metaphors [116] but highlighted that for metaphors to be effective they need to be perceived as directly related to the performed movement [41]. These works have shown the effects of movement sonification on emotional state related to BP that in turn facilitates movement, e.g., changes in fear, to feel safer and more comfortable during movement therapy [25]. The study combines both approaches: movement sonification to alter BP in inactive people is used to support their psychological and emotional needs related to PA [6]. With this approach, this thesis aims to build on the user’s perceived physical capabilities and in turn facilitate changes in PA. Thus, answering the call of [7] for tools to modify behavior and reduce frustration of people who feel incapable or do not know how to act to change their level of PA.

Following the approach that exploits bottom-up sensorimotor mechanisms related to BP through the use of movement and auditory feedback to evoke changes in BP, a second study was conducted, using metaphorical sounds (“Water”, “Up”, and “Wind”) with a “leg lift” movement. In the study, a first questionnaire showed the following effects, which are summarized in the "leg lift" column in TABLE 9.1. With the "Water" and "Wind" sounds, participants reported the senses of increased strength, easiness, capability, agility, lightness, and also that their movement felt more fluid. Secondly, the "Up" sound shared some effects observed with the other sounds: participants reported the feelings of increased capability, lightness, agility, and easiness in the movement, as well as a better sense of proprioception. However, this last effect affected the actual movement angle: participants with the "Up" sound lifted their leg to a smaller maximum angle, which it was attributed to the fact that the sound made them perceive that their foot had reached the objective angle, leading them to stop the movement before actually reaching the objective angle. In addition, with regards to the effects on emotional state, the "Water", "Wind", and "Up" sounds seem to increase motivation.

It is worth mentioning that in this second study, a second questionnaire was used, allowing participants to compare all sound conditions and reflect on their body sensations during exposure to the sounds. This second questionnaire confirmed that the "Water", "Wind", and "Up" sounds evoke a sense of increased strength. What is interesting in relation to this is that the behavior data showed that for the "Water" and "Wind" sound, participants spent more time lifting their leg and reached higher mean angles. In the case of the "Water", "Wind", and "Up" sound, participants spent more time during the downwards movement than "No sonification". This study showed how a specific sound, such as "Wind", "Water", or "Up", could have different effects when accompanying different movements. Therefore, future work is needed to understand the sound characteristics in different contexts (i.e., type of exercise). It is worth mentioning that the observed effects of sound conditions on the emotional state, bodily feelings, and movement behavior in the first two studies, are presented in the form of quantitative findings from controlled studies. Those works called for further work to investigate through qualitative research the connection between specific sound characteristics and specific perceptions of one's body and PA and to investigate how the different bodily feelings may support changes in movement behavior and PA. At the same time, quantitative studies were still needed to investigate other potential effects of sounds on BP, for instance, to influence proprioception [16], or different aspects of it, such as proprioceptive awareness or confidence in one's body position in space [160], or accuracy in reaching a target position [161].

In study 3, the interaction between the sound and the movement differs from those employed in studies 1 and 2 in which direct movement sonification was used, by tracking body movement and mapping it into real-time auditory feedback providing information on the movement itself. By contrast, the experiments in Study 3 do not rely on continuous real-time adjustment of the sound once it has been triggered. This approach differs also from the movement sonification used in many previous works with different cases of use [116], dance (e.g., [217]), sports (e.g., [21], [139]), general PA (e.g., [178], [185]) and physical rehabilitation (e.g., [218], [219]); Thus, Experiment 1 focused on ascending and descending pitch sounds because of their reported association with changes in motion along the vertical plane (i.e., upwards and downwards motion). Participants lifted their arm with the aim to reach a target position, and only the upwards part of the movement was paired with sounds. Overall, Experiment 1 showed that the changing pitch sounds, as compared to a constant sound, made the participants feel less confident about their arm position, and impacted on the angle reached by the arm, but not in the accuracy in the reached arm position (see TABLE 7.12).

It was previously observed in quantitative experiments, that is, in "leg lift" experiment, the participants perceived to have better proprioception, and they reached a lower angle. However, this may mean that the sensation of having better proprioception evoked by the "Up" (musical increasing pitch) sound affected the accuracy of the movement, and whether participants knew that they had actually reached the target angle. Experiment 2 results confirmed that the musical sounds changing in pitch had also an effect on proprioception. Participants felt more confident about their arm position with the "Up" sounds, which also led them to reduce their speed during the upward movement. With regards to the emotional state, the "Up" sound increased participants' comfort during the movement; nevertheless, since Experiment 2 did not include a measure of emotional state (beyond comfort and motivation), the current data does not allow us to make any conclusive remarks in change in people's overall emotional states and/or change the multisensory integration (e.g., [220]).

On the other hand, in Experiment 3, changes in the absolute frequencies of the changing pitch sound were added to explore potential effects on BP and movement behavior. Findings showed that the higher frequency sound resulted in increased senses of happiness, lightness, easiness of the movement, and reduced the feeling of tiredness. Moreover, the higher frequency sound increased the motivation in participants and made participants' arm raise movement reach a higher peak angle. It is possible that the body sensations evoked in this experiment with high pitch sounds motivated the participants to reach the arm to a higher position.

Based on the findings of Experiment 2 and 3, future research should include emotional measures, both self-report and physiological real-time measures (as in [17]), to clarify the origin of the interaction between musical sounds changing in pitch and their changes in the absolute frequency range, to understand the effects on people's emotional state and motivation to achieve better performance when listening to these sounds.

These findings are useful to understand how music and sound trigger changes in perceived body capabilities and positive feelings about one's body. In this regard, this work contributes to the human-computer interaction and sonification research that focuses on inviting movement and helping to overcome psychological barriers related to BP and PA, for instance the fear of injury or lack of confidence in one's movement often experienced by people undergoing physical rehabilitation of conditions such as chronic pain [25], [27], [41], [108]. Lastly, embedding these psychological factors related to BP into the design process of applications to support dance or PA opens opportunities for movement expression and clinical applications.

9.2. Qualitative studies

In the last step of this research work, the impact of different metaphorical sonifications on BP and PA for two populations has been explored. Through two qualitative studies, one with physically active participants over multiple days (study 1 or AP-study) and one with physically inactive participants in their homes over two weeks (study 2 or IP-study), several effects have been identified and enabled by five different metaphorical sounds present in the wearable device SoniBand. In study 2 (IP-study) the profiles of physically inactive participants were described from the interviews to select them, allowing to see the daily life and body-related barriers to PA, understanding their bodily sensations and the difficulty to overcome or change their bodily sensations to positive sensations during PA. After the profiles, the body sensations presented during the studies were identified based on the participant, the day, movement, and sound. Considering this, the effects on number of repetitions and most important bodily perceptions elicited by the different sonification conditions during PA can be seen in the table below (TABLE 9.2).

Moreover, once study 1 and 2 were analyzed to understand participants' thinking, similarities and differences between populations were identified, highlighting the effects of the different sounds on the perceived qualities of strength, control, fluidity, weight, effort, and joy. These are visualized in TABLE 8.8 and TABLE 8.9. The results mainly show how the sound effects vary from one population to another, characteristics and metaphorical qualities of the sound. With regards to similarities between populations, the "Wind" sound demonstrated to affect positively both populations, impacting the perceptions of control, fluidity, lightness, and joy; and increasing the awareness of movement pace in participants, helping them gauging their pace and following a rhythm. These body sensations are supported by sound characteristics, such as a continuous sound that sounds during the whole movement increasing and decreasing in frequency and intensity. With regards to differences between populations, the "Water" sound affected the perceived movement control and fluidity in IP participants, increasing both body sensations; meanwhile for AP participants, this sound decreased those sensations, due to the fact that for AP a slow rhythm reduced their normal pace, while for IP the sensations of being in real water helped them to feel these body sensations positively.

TABLE 9.2: EFFECTS ON REPETITIONS AND FEELINGS MORE OFTEN PRESENT DURING THE DIFFERENT SONIFICATION CONIDTIONS IN THE IP-STUDY.

			Sonification			
Dimension		Predicted effects	Wind	Mechanical	Water	Beep
Behavior (number of repetitions)		> number of reps	☑	✗	☑	✗
Bodily and emotional feelings	Feelings about the body	Strong	☑	☑	☑	✗
		Weak	✗	✗	☑	☑
		Flexible	✗	✗	☑	☑
		No flexible	✗	☑	✗	✗
		Fluid	☑	☑	☑	☑
		No fluid	✗	✗	✗	☑
		Quick	✗	✗	☑	✗
		Slow	✗	☑	☑	☑
		Light	☑	☑	☑	☑
		Heavy	☑	☑	☑	☑
	Feelings about the movement	In control	☑	✗	☑	☑
		Not in control	☑	✗	✗	☑
		Agile	☑	✗	☑	✗
		Not Agile	☑	☑	✗	✗
	Emotional feelings	Pleasure	☑	☑	☑	✗

The results of the qualitative studies, with regards to the similarities and differences between populations, as well as to the identification of the qualities and characteristics of sonification that impact on the perception of body movement and PA, allowed for design considerations, emphasizing those for the physically inactive population, see next section.

9.3. Design Considerations

Results of the quantitative and qualitative studies reveal certain trends in how the sonification' principles and characteristics impacted the perception of body movement and the PA. First, they were articulated as design considerations that synthesize how it is possible to alter BP, proprioceptive awareness, and movement behavior through metaphorical sonifications. Secondly, the relationship between certain sound qualities/characteristics and perceived effects in the quantitative and qualitative studies, emphasizing those for the physically inactive population was articulated. The aim was to offer directions for further design/research in sonifications to increase adherence to PA.

9.3.1. Affecting Body and Movement Perception

This thesis[15] synthesizes how the movement sonification effects on BP and movement behavior of the quantitative and qualitative studies. This section is grouped under five sonification considerations (i.e., being personally rewarding, supporting the sense of agency, positive/negative metaphorical associations, and particular sound characteristics, proprioceptive awareness). The effects were often shared between physically active and inactive populations, but what enabled them sometimes differed.

9.3.1.1. Personally rewarding

Sounds that were personally rewarding positively affected the feeling of **joy in movement** for both physically active and inactive populations. For the physically inactive population, they increased their **feelings of strength** and **decreased the perceived effort**. Yet, what was considered personally rewarding sometimes varied among both populations: for the physically active population, it often related to personal preferences and sounds being perceived as playful (e.g., Tone). This relates to a previous finding that music-based sonifications encourage continuation in people with chronic pain (Newbold et al., 2016). For the physically

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[15] The qualitative design considerations were written in collaboration with a Ph.D. Student from Uppsala University, Laia Turmo.

inactive population, personally rewarding sounds were those which were natural and fostered feelings of comfort and relaxation (e.g., “Water”, “Wind”) as was observed in quantitative studies of this thesis and in [187], and which offered a distraction from the exercise (e.g., “Water”). In quantitative studies, the sensation of effort during the “walk” exercise for a physically inactive population with the “Wind” sound; participants reported feeling excitement, and their heart/breath accelerated together with a sense of less happiness, which can be related to the feelings of being applying more effort in the exercise. On the other hand, the “Wind” sound resulted in a reduction in tiredness and increased sense of control over the movement. The follow-up results related to the “thigh stretch” exercise with the “Wind” sound (performed also in the IP-Study), corroborated that the “Wind” sound made participants feel also less tired and more comfortable, moreover more motivated, and in this case happier. In addition, the feeling of strength in “leg lift” exercises for the inactive populations with the “Water”, “Wind”, and “Up” sounds showed to evoke the body sensation of strength along with other bodily sensations, such as feelings of agility, lightness, and capability, and increasing motivation to perform the exercise. The “Water” sound also showed to evoke a sense that muscles were working harder but at the same time participants perceived their movement as being more fluid and easier with this sound. Also, see Section 9.3.2.5 on Extending the sonification in time.

Lastly, this relates to previous studies [38], [41] that mention that water could be used to stretch on stressful days and to distract from pain. Sounds that made participants confused or gave them a sense of urgency were not deemed as personally rewarding (e.g., Beep). Beep was used in previous work that suggested future research to study the sound effects of longer exposure to it [21], as it had a notable effect over the BP. In other cases, the beep’s tone and structure might be negatively perceived by the inactive population, given that it does not afford any positive metaphorical association, and participants only feel hurried – on top of not enjoying the exercise per se [21], [23].

9.3.1.2. Sense of agency

Sounds that support a sense of agency (e.g., “Wind”) increased feelings of **strength** and **fluidity** in both populations. For the physically inactive population, these sounds enhanced the **feelings of joy** when moving and the feeling of being **in control** of their body. When the sense of agency was not well supported (e.g., unsynchronized), the **feelings of joy and control decreased** for both populations. Prior work has shown that a sense of agency is needed to evoke changes in BP (e.g., [15], [17]). The results extend those by showing specific BPs that can be elicited if the sense of agency is respected.

9.3.1.3. Metaphorical association

Sounds that fostered metaphorical associations with positive imagery, feelings, or situations (e.g., "Wind" sound), increased the sense of being **lighter** and of movement **fluidity** in both populations. This was shown in previous work [126], which showed effects of perceived movement fluidity, energy, and expressivity, but this thesis contributes to the results related to the sense of speed (fast/slow). For the inactive population, these associations also resulted in perceiving more in control of their body and that the exercise was **less effortful** (e.g., "Water"). In quantitative results, the "Water" and "Wind" sounds showed to positively affect the feeling of flexibility in the "thigh stretch" exercise for the physically inactive population. In particular, the "Water" sound helps in feeling flexible, in addition to affect the sense of speed, agility, fluidity, which seems to go together with feeling less tired and perceive the exercise easier. Also, the "Wind" sound helped to increase the sense of flexibility, which may be related to the sense of having a higher agility and feeling the movement more fluid and easier. Moreover, these sounds had a positive effect on emotional state: the "Water" and the "Wind" sound are the sounds with more capability to evoke motivation, happiness, and comfort. Associations to negative imagery decreased **feelings of joy** and the sense of **movement fluidity** in both studies. However, in a particular case (Mechanical) although the sound elicited negative feelings, it did increase the feelings of movement **fluidity** and **coordination**, while it also increased the feelings of being **heavier.**

9.3.1.4. Particular sound characteristics

Sounds that presented gradual changes in intensity and frequency and that played throughout the movement trajectory (i.e., "Wind" and "Mechanical") increased the feelings of movement **fluidity** in both populations, as in [126]. For the inactive population, the high frequency of the Wind underpinned feelings of being **lighter**; and the discrete Mechanical sound playing throughout the movement enhanced the sense of being in control [25], [141]. The latter finding extends previous studies with this sound and proposed design consideration of proprioceptive awareness (see next sonification consideration), showing that it led participants to perform their movement slower, which is related to an enhanced sense of control/proprioception.

9.3.1.5. Proprioceptive awareness

The sound that was capable of affecting proprioceptive awareness in inactive populations was a sound with a spatial metaphor, i.e., the "Up" sound.

- The "leg lift" exercise accompanied by the "Up" sound made participants increase their feeling of being aware of where their foot was during the movement (i.e., proprioceptive awareness) while also reflected in participants reaching a smaller angle. A possible relation between a smaller angle with an increase in confidence in proprioception could be answered by looking into previous works that have shown how the sense of position and location of one's limbs in space can be altered by manipulating the perceived distance of action sounds with respect to their actual distance [15], [61], or by changing pitch sounds [16]. This result suggests the auditory information influenced participants' proprioceptive awareness and that could be reflected in a smaller angle reached: once the sound stops sounding the person stops moving. In addition, this extended the sense of accomplishing a movement as introduced in [25], [176], where it was shown that musical structures may affect the feelings of wanting to continue or end movement, see Section 9.3.2.4 Signaling the movement start and end.
- A follow-up study (Study 3) presented new versions of the "Up/Ascending" sound, adding new qualities in three different experiments. Pitch change (in original pure tones, and a musical "Up" sound), change in harmony (Musical_up and Musical_down), and absolute frequency range (Higher or lower frequencies).
- Whether the purpose is to enhance the confidence in one's proprioception, it is recommended to use Musical sounds, due to that when they were compared with pure tones, the effects on proprioceptive awareness and other body feelings were replicated and it was shown that the Musical sounds resulted in an increased sense of comfort as compared to pure tones [16].
    - For a change in performance, it is possible to combine musical sounds with higher frequency sounds; this combination allowed to increase the amplitude

of the participants’ arm raise movement, making the arm reach a higher peak angle.

    - These effects are complemented with changes in other body feelings. In general, participants found the musical sounds were more comfortable. But also, they felt enhanced happiness, lightness, fluidity, flexibility, motivation, reduced tiredness, and found the movement easier with the higher frequency during the “side arm raise” movement. This point is complemented by the first sonification consideration (Section 9.3.1.1 personally rewarding experiences).

- On the other hand, the “Water” and the “Wind” sounds seem to motivate participants to reach higher mean angles. These results are extended with those results from the qualitative studies where it was shown the link between sound and movement characteristics (see Section 9.3.2.2, Sonifiying the whole movement through gradual changes).
- Finally, the “Mechanical” sound accompanying the “thigh stretch” exercise made participants feel a higher sense of proprioception. This is reflected in participants being able to reduce their leg lowering time while listening to the “Mechanical” sound. These results extend previous work by adding a sound able to inform about the leg movement when going up and down (trajectory) and leading to enhanced proprioception, as in [41] where design principles were proposed for sonified exercise spaces. For instance (Principle 2 and 4), to enhance progress and facilitate awareness of body position with anchor points and boundaries, they proposed an ascending scale of tones in order to evoke a sense of progress to a goal or to an end of the movement. See also Section 9.3.2.2, on sonifying the whole movement through gradual changes.

9.3.2. Affecting the Physical Activity

This section synthesizes the effects of particular sound characteristics on the PA to complement the initial design considerations of the quantitative results (Section 9.3.1). The effects are grouped under five sonification considerations. TABLE 8.9 summarizes what characteristics underpin particular effects.

9.3.2.1. Affecting acceleration/velocity and time

Here, it was designed considerations to take into account when behavioral changes need to be evoked for future research, based on the results of quantitative studies.

The "Can-crush" sound can change bodily movement in the "walk" exercise, as it can affect the time that the foot is in contact with the ground, in the physically inactive population. The "Can-crush" sound, which replicates how an aluminum can is crashed against the ground, led participants to change their gait behavior similarly to how the frequency alteration in walking sounds change gait patterns in [17], [33]. In particular, the "Can-crush" made the participants spend less time in contact with the ground. "Can-crush" in the "walk" exercise only evoked a sense of flexibility; this result invites to explore whether the fact that the "Can-crush" elicited a sense of flexibility could be related to a change in the gait pattern.

The "Mechanical" sound can change the bodily movement during the "thigh stretch" exercise. With this auditory feedback participants are able to reduce their leg lowering time while listening to the mechanical sound.

With the "Water" sound during the "thigh stretch" exercise, participants changed their bodily movement. This sound resulted in an increase in upwards deceleration and in downwards acceleration, that is, participants decreased the acceleration of the movement when lifting the leg, as well as increased the acceleration of the movement when lowering the leg.

"Water" and "Wind" sounds in the "leg lift" exercise seem to help participants to spend more time lifting the leg as in [221]). This work [221] presents the use of sonification in a biceps curl exercise, and showed that the participants that received sonification feedback exercised at a slower pace than the participants who exercised without feedback. Here, the findings extended the work of sonification that can provide changes in behavior, e.g., slower pace [221].

These findings extend previous studies with this sound and connect to another proposed design consideration to increase proprioceptive awareness (see Section 9.3.1.5), as leading participants to perform their movement slower may enhance the sense of control/proprioception.

9.3.2.2. Sonifying the whole movement through gradual changes

In both qualitative studies, sounds that sonified the movement entirely (i.e., they played both during the movement trajectory and kept playing during the start and end calibrated positions) and clearly signaled the angular **changes** between the start and end body positions through changes in frequency, intensity, speed, or timbre, positively impacted the participant's **awareness on the movement pace** and their ability to use the sonification to **gauge and adapt their pace** and create and **follow a rhythm**. These findings relate to [23], a study on the effects of sonification of rowing movements which suggested that one of the reasons for the observed improvement in the rhythm of the crew was the change in pitch and intensity of the sonification. However, in that study, they did not go in-depth about how the sound characteristics altered the movement behavior. This work extends that work by linking particular sound characteristics to movement characteristics.

9.3.2.3. Sonifying the movement trajectory through gradual changes

In contrast to the previous section, sounds that sonified the angular changes only during the movement trajectory with changes in frequency, intensity, and speed (i.e., Mechanical, Wind) positively impacted the **participants' awareness on the movement process**, as in [41] where these musical sonifications aim to concurrently announce progress in home activities. This was particularly successful with discrete sounds because participants could better discriminate between phases of the sound, and relate a specific point of the movement trajectory to them. Continuous sounds presenting these characteristics were perceived to offer a global **guide on the movement process**, almost fostering the movement rather than providing feedback on specific points within the trajectory.

9.3.2.4. Signaling the movement start and end

Sounds that were able to clearly signal the start and end of an exercise positively impacted the participant's awareness of, and ability to gauge, their movement at those points. This signaling came to realize through two ways: 1) sounds that played throughout the whole movement and which changes in frequency, intensity, and speed reached their maximum and minimum values at those calibrated points; and 2) sounds that only played at the calibrated positions. This extends previous works that highlighted that endings are needed to increase movement reward and self-efficacy in stroke rehabilitation and populations with chronic pain [39], [41], [187].

9.3.2.5. Extending the sonification in time

Discrete sounds that were only played at the start or end of the exercise (i.e., water's splashes, tone), but kept playing some seconds after the participants had reached that position, created the impression in participants that they had to wait for the sound to end prior to resuming the exercise [41]. This **slowed down** the participants' pace, and subsequently **increased their perceived effort**. Discrete sounds that played throughout the whole movement (i.e., Mechanical), presenting changes in frequency and speed, but that did not stop playing once the maximum calibrated position had been reached by the participant, encouraged the participants to push the set boundaries (i.e., attempting to surpass the calibrated positions), which often resulted in more challenging exercise forms (e.g., squat deeper). In quantitative studies, the "Can-crush" sound which is a discrete sound, it is only played in each step, inviting participants to move continuously in order to listen to the sound again [41], it showed the potential to evoke the sense of being more flexible and resulted in participants spending less time in contact with the ground, which means less rest time for the feet therefore more PA and more effort applied. The sense of flexibility and change in gait could be related with the feeling of constantly crushing aluminum cans. The "Mechanical" sound in the "thigh stretch" exercise, showed to affect the sensations of heaviness, and tiredness that could be related to muscle working harder leading to a sense of strength.

This finding links to previous work [22] showing that people who struggle in PA engaged to perform deeper squats with sonification where the start/end position was stable.

9.3.2.6. Personally rewarding

Sounds that were perceived to be such positively impacted the participant's willingness and ability to finish the set of repetitions of the exercise, as well as to do more repetitions [22], [41].

9.3.3. Linking Effects on Body/Movement Perception and Physical Activity

Following with the design consideration based on the quantitative and qualitative studies. The results showed that sounds that were generally not liked by the participants (e.g., Mechanical in both qualitative studies, due to its association with negative imagery) were nonetheless able to positively impact their PA (e.g., increase awareness on movement trajectory) due to their sound characteristics. While ideally both would be obtained [22], [41] (a well-liked sound with positive effects, as the Wind in studies), it has been shown that there might not be alignment between the two. This requires further investigation on the longer-term effect on movement quality (of PA) and might influence future design interventions, see TABLE 9.3.

TABLE 9.3: OVERVIEW OF THE EFFECTS ENABLED BY PARTICULAR SOUND CHARACTERISTICS.

Sound Characteristics		**Movement Pace**				**Movement Structure**					**Movement Endurance**	
		Increase Awareness	**Gauge & Adapt**	**Follow rhythm**	**Slow down**	**Awareness start/end**	**Gauge start & end**	**Awareness process**	**Guide on process**	**Push boundaries**	**Finish reps**	**Do more reps**
Structure	Continuous										Personally rewarding	
	Discrete				X			X	X	X		
When it sounds	Trajectory							X				
	Start/end				X	X	X					
	Both	X	X	X		X			X	X		
Changes in:	Frequency	X	X	X		X		X	X	X		
	Intensity	X	X	X		X		X				
	Speed	X	X	X	X			X	X	X		
	Timbre	X	X	X		X						

Personally rewarding sounds positively impacted both the body and movement perception and PA, as it can be observed in the quantitative studies. Yet, that was observed in the qualitative studies, what is personally rewarding can be very individual, and dependent on a myriad of aspects that range from positive associations being traced to the sound to the help that it is perceived to offer. These, in turn, may depend on the socio-cultural context of the person, their body capabilities, and their emotional states [6]. In future design interventions, there is a need to consider how individual factors influence the effects of sound feedback [33].

Overall, the quantitative results as well as analyzing both populations allowed us to identify the shared effects of the sonifications. Both the results and the tactics above present (sometimes) differences regarding how these effects came to be for each population. Although future work is needed, this research sees value in these shared findings. That similar sonifications elicited similar effects could indicate that what works (or does not work) for one population may also do so for the other – opening up to explore the use of metaphorical sonifications to support the physically inactive population towards a more physically active lifestyle. Still, the work highlighted some differences between the two populations possibly due to different physical needs and how such different needs have led the person to focus more on a certain aspect than other; e.g.: the inactive people perceived the gear-movement of the Mechanical sound as it contributed to enhance a sense of control and progression, while the active people did not need such sense of control given the simplicity of the movement and instead focus on the misalignment of the metaphor with their fluid movement. This is in line with new theories of emotional experience, seeing emotions as concepts constructed by multiple brain processes and shaped by factors that characterize people's previous experiences and needs [222]. As such it is important to study not just the common patterns but the variability to better understand the factors that contribute to the effects of sonification that started to emerge in [33], [176].

These results align with somatic literature in HCI (e.g., [223], [224]) in illustrating that movement and subjective experience intertwine.

The movement is at the core of, and shapes, the subjective experience of the world [224]; and interactive technology has the potential to support and affect people's own bodily understanding [223], [224]. In that light, the findings corroborate that the metaphorical sonifications enhanced the participants' sensory appreciation of their own body: their proprioception and body focus [223], [224]. These findings are in line with other, artistic-focused, somatic works (e.g., [223]), in which providing a non-prescriptive, augmented feedback modality (sound) enabled participants to make sense of their own bodily experience. Despite the inherent subjectivity in movement experiences, the results show that participants individually came up with similar use strategies of the sonifications (e.g., pacing themselves, gauging the start and end of the movement); and experienced similar effects (feeling the sounds offered a guide on the movement). This points towards shared commonalities among individual and subjective somatic experiences, which emphasizes the potential of the results to be relevant in other use contexts.

10. CONCLUSION

This chapter presents the conclusion of this thesis work. First, the contributions of this thesis are presented and discussed. Then, the limitations of the thesis work and possible future work are discussed.

10.1. Contribution

This thesis is fundamentally concerned with and contributes to the fields of HCI, cognitive neuroscience research, and technology for PA. By proposing a novel approach to address psychological barriers of people with a low level of PA, this thesis contributes to the literature on HCI, technologies for PA, and psychological barriers, see Contribution 1. It contributes to the field of interactive sonifications by bringing psychological barriers to the center of the design of technology for supporting PA, see Contribution 2. Contributions range from the design and evaluation of sonifications with metaphors and a set of mapping with the potential to alter BP, see Contributions 3 and 4. This thesis contributes with a set of sonifications considerations for sensory technologies to alter PA, see Contribution 5. This thesis contributes two wearable devices based on psychological barriers related to BP and PA, see Contribution 6. Lastly, this thesis shows the possible impact on society and psychological wellbeing of adults, see Contribution 7.

In the next sections, the seven main contributions made by this thesis are detailed.

10.1.1. Contribution 1: A novel approach that combines interactive movement sonification and bottom-up multisensory mechanisms to address psychological barriers to PA related to body perception.

This thesis introduced the first evidence of the application of a new approach which exploits bottom-up multisensory mechanisms related to BP in combination with the use of interactive sonification. This approach presented evidence to address psychological barriers to PA, with an emphasis in physically inactive adults. This approach focuses on changing people's BP through real-time movement feedback based on metaphorical sound to address negative/distorted BPs in the context of PA [11], [14], [21], [102], [223].

The interactive sonification novelty is in the approach of tailoring feedback to address psychological barriers to PA through improving perceived capabilities (i.e., a sense of what one's body can do and how the body can perform). This contrasts with other traditional works on rehabilitation and PA applications which focus only on supporting physical capability [23], [139] or motivation [79], [99]. In this thesis work, interactive sonification was used to bring an awareness of one's body moving during PA, as well as to elicit changes in BP.

In bringing together interactive sonification and bottom-up multisensory mechanisms related to BP, the potential of the approach to facilitate PA through overcoming psychological barriers related to BP became more pronounced and led to the next contribution.

10.1.2. Contribution 2: A synthesis of psychological barriers to PA related to body perception in physically inactive adults and strategies to overcome them.

A taxonomy was proposed (Chapter 5) in order to accomplish the **SO1** (To *investigate* what barriers to PA are mentioned in studies oriented to the design and evaluation of technologies to promote PA, especially those related to BP). As well as to answer the **RQ1 (***What are the psychological barriers to physical activity related to body perception and what strategies can be used to overcome them by physically inactive adults?)*

Different psychological barriers to PA related to BP were obtained from the literature, surveys, and work with focus groups, resulting in barriers such as lack of confidence in one's body, low perceived cardiorespiratory endurance, feelings of being stuck, etc., and these barriers were analyzed. The taxonomy starts (step 1) by identifying the barriers based on the above-mentioned sources, and ends (step 4) with the output of strategies to address them that emerged from the literature search and relevant movement-sound mappings in this context. The identification of psychological barriers related to BP and PA has been the main objective for the development of the taxonomy; this is due to the fact that the literature review (of Chapter 4) showed that aspects such as motivation or social competence are only a small contribution to overcome barriers to PA [69], [73], [74] and it could be observed that the negative perception of one's own body is also an important aspect for the practice of PA. For example, the lack of confidence in one's own body, involving feelings of fear, or feeling incapable of performing an exercise, or generating a feeling of extreme difficulty, can impact the involvement in PA [27]. Therefore, strategies for changing BPs were proposed using sonifications to act upon different negative BPs (e.g., increasing perceived agility and flexibility, or decreasing feelings of tiredness) and motor behavior during PA (i.e., “walk”, “thigh stretch”, “leg lift”, “steps up”) in physically inactive adults.

This synthesis of evidence of psychological barriers that prevent PA contrasts with the approaches to design technologies to support PA reviewed in Chapter 5, Section 5.1.1, that focus on overcoming psychological barriers using facilitators such as tracking activity, goals, and rewards. Even the literature reviewed in Chapter 4, shows some research works focused on psychological barriers but mainly on social (competition), personal (time), and physical barriers. There is little work on other kinds of psychological barriers related to BP. While self-monitoring of PA, planning, and goal setting are useful, the taxonomy point out that people may experience negative BPs affecting their involvement in PA, as they may have a lack of confidence in their own body capabilities or abilities to be physically active.

The analysis of these barriers and strategies that emerged from this research work not only led us to better understand the needs for technologies to assist with psychological barriers, but to recognize that it is needed to rethink the role of technology in supporting PA in physically inactive people. Therefore, this knowledge allowed us to propose strategies and design a wearable device prototype embedding a movement-sound mapping palette. This rethinking of technology led to the next contribution.

10.1.3. Contribution 3: A set of use cases, the design, and use of movement-sound palettes (mappings) for specific movements recommended in PA programs.

From Chapter 5, 6, 7, this thesis investigated the use of wearable devices embedding mappings to support particular exercises in controlled studies. In order to accomplish the **SO2** (To *design* a portable device with a movement-sound palette to alter the BP, emotional state, and motor behavior patterns of physically inactive adults.), and to answer the **RQ2** (*Which movement sonification strategies, through changes in body perception, have the potential to support PA to overcome psychological barriers to PA?)* and **RQ3** (*How can we integrate movement sonification in wearable technology for PA and evaluate it in adults?).* These studies showed that through interacting with the mappings it was possible to alter perceived physical capabilities during PA.

An explorative study (**RQ2**) allowed for the design and evaluation of movement-sound palettes (mappings) integrated in a prototype. The first exploratory study (using the prototype

MagicShoes) allowed us to observe the potential effects of the mappings related to the potential changes in perception of the body. Based on the results, the wearable device and their mappings were re-designed. Three quantitative studies (**RQ3**) were carried out to evaluate the re-designed mappings which were integrated into two wearable devices - a refined device, now called SoniShoes, and a new device named SoniBand - with the aim of identifying the effects of the respective mappings for a specific movement, that is how the sounds impact on body and movement perception.

The mappings in quantitative studies were defined according to the type of exercise and the body capabilities targeted. For instance, on the one hand, “walking” is a low-risk exercise that covers cardiorespiratory endurance, strength, and speed/agility; on the other hand, the “thigh stretch” and the “leg lift” exercises target flexibility and strength respectively [140]. Therefore, three use cases were defined as part of the set of use cases taking into account three aspects of physical fitness: “walking” (which links to general physical fitness), flexibility and strength. Lastly, the “side arm raise” exercise targets general warm-up and strength [140]. Therefore, a fourth use case was defined based on the results of the sound effects in the first three use cases: the “Up” sound accompanying body lifting showed its potential to make an effect in proprioception. This sound contains a ballistic metaphor, that is, it is associated to movement in the vertical axis (e.g., ascending), and when it accompanied body movement it made people report feelings of “being pulled” by the sound (which is referred to at the beginning of this thesis as “body pulling”). Thus, for this thesis, it was decided to include a use case to show the effects of this sound on people’s proprioception and how it affected their confidence in knowing the position of their limb during movement.

Other works on interactive sonification have shown its potential to support various activities in different contexts such as sports [23], [128], physical rehabilitation [39], [108], or dance [217]. However, these works mainly focus on providing movement information, or on performance during PA. In this thesis interactive sonification, in addition to providing information during movement, focuses on facilitating PA through changing negative perceptions of the body into positive ones and changing the perception of lacking physical capabilities to perform PA.

The use cases provide evidence of how each sound makes an effect on particular perceived physical capabilities and body feelings. However, to complement use cases further research was needed with the aim of grasping the sound effects in other contexts, which in this research work led to a qualitative evaluation and led to the next contribution.

10.1.4. Contribution 4: A set of movement-sound mappings for sensing technology with the potential to alter BP to facilitate PA in the home.

In Chapter 8 was accomplished the **SO3** (To *evaluate* the short-term and long-term effect of the movement-sound palette on BP, emotional state, and motor behavior in studies with physically inactive adults). It was addressed the **RQ4 (***How can interactive sonification be used in the long-term and in everyday environments (i.e., in the wild) to promote physical activity in physically inactive adults?)*

A set of mappings with the potential to alter BP were identified specifically in the exploratory and quantitative studies (Chapter 6 and Chapter 7). These mappings were designed to act upon different BPs (e.g., perceived agility, flexibility) and to enhance the emotional states related to such BPs and motor behavior during PA (i.e., “thigh stretch”, “leg lift”, “side arm raise”). The qualitative studies (Chapter 8) involved the identified mappings, two different populations and contexts (work and home), interviews, and body maps. These different elements were used to ground the participant’s reflection on the sonifications’ effects on body/movement perception and on the PA.

This qualitative evaluation was conducted first to understand how the different qualities of the sounds linked to different qualities of the PA, e.g., the rhythm of movement. Moreover, the studies aimed to observe the difference between populations and understand the importance of focusing on a user-centered design. Following this, results showed qualitative insights on how the body and movement perception, and PA were affected by different metaphorical sounds in participants from two different populations. Prior works have used sonification to lead or help body movement (e.g., for informing and guiding movement), for example in the context of rehabilitation [41], or to enhance body awareness in the context of movement exploration or art [223], without looking into BPs. This thesis work contributed to a longitudinal study which focused on exploring the facilitation of PA within the home.

10.1.5. Contribution 5: A set of design guidelines for sensory technologies to inform future work on movement sonification to alter PA.

This thesis, as discussed in first chapters, encountered a lack of research on psychological barriers for designing PA technologies beyond HCI works that focus purely on personal or social facilitators for PA. First of all, this current under-research in PA technologies led us to propose an initial set of strategies and a movement-sound palette (mappings), based on a taxonomy that makes a synthesis of psychological barriers related to BP and PA. The novelty of this work lies in the use of metaphorical sonifications [116] to address negative BPs in the context of PA [14]. The various effects of metaphorical sonifications on BPs have been measured quantitatively, in controlled laboratory studies (Chapter 6-7). These were followed with qualitative studies (Chapter 8) that were performed considering physically active and inactive populations. This thesis contributes with a set of design considerations regarding particular sound qualities and characteristics to inform future research on metaphorical sonifications. These contribute to the body of work on sensory feedback, and in particular movement sonification [17], [25], [27], [33] to alter BP. Through this contribution, and the way it was approached, the aim was to bring body awareness to the center of PA, beyond the motivation and monitoring of PA which is the common goal of PA technology. The proposed set of design guidelines considering both physically active and inactive populations, although emphasizing those for the physically inactive population, could potentially be applied to other conditions based on the literature (e.g., athletes), although this needs to be further investigated.

10.1.6. Contribution 6: A wearable device for body monitoring and movement sonification, towards promoting PA.

This research contributed with technological prototypes: two wearable devices (SoniShoes and SoniBand) integrating various sonifications (Water, Wind, Mechanical, Tone, Ascending and Descending sonifications) were developed and evaluated by users:

- SoniShoes, which is a refined device (based on the MagicShoes prototype available at the beginning of this thesis work) and desktop version that allowed controlled studies.
- SoniBand, which is a compact version to be used in ubiquitous environments, allows for setting-up various sonifications through a graphical user interface, and for calibrating the device to the range of movement to be sonified for a specific person.

Both devices are contributions to the application domain studied in this thesis. Both devices allowed body monitoring and movement sonification; and supported the design and evaluation of mappings to promote PA in physically active and inactive people.

10.1.7. Contribution 7: An impact on society, economy, and the psychological wellbeing of adults.

Finally, this research shows potential to contribute to the psychological wellbeing of users, and by that impact on society. The results are related to a potential to promote exercise in inactive adults and with it an improvement of the emotional state through a better perception of their own body, leading to a better predisposition for PA.

Physical inactivity can have profound health consequences for people. Physical inactivity in adults can contribute to the prevalence of health problems (e.g., cardiovascular disease or diabetes), raise high blood pressure or lead to being overweight [28]. In turn, providing a potential reduction in diseases associated with physical inactivity, could translate into a potential reduction in direct costs (€80 400 million per year) by reducing the need for medication, as well as further reductions in indirect costs in healthcare [225].

10.2. Limitations and Future work

Although the research achieved the objectives, this research work presents limitations. Some considerations that can be taken into account in planning future work in different topics are given below:

10.2.1. Toward new uses cases, exploring SoniShoes and SoniBand

This thesis presented use cases as controlled studies that were centered on perceived body sensations or capabilities, such as flexibility, strength, and proprioception, through specific kinds of movements, i.e., “thigh stretch”, “leg lift”, and “side arm raise”, which worked well with metaphorical sonifications generated by SoniShoes and SoniBand. On the one side, the set of use cases allowed us to investigate quantitative changes related to BP during PA, in a limited number of exercises and in only two population categories: physically active and inactive adults. This thesis explored qualitatively other types of exercises (e.g., exercises of warm-up or cardiorespiratory endurance) and sonification effects on particular body and movement perception (sense of control or progression). Nevertheless, the implementation of several other use cases with qualitative and quantitative evaluations could be explored by considering other exercises or in other populations (e.g., stroke).

Another limitation in this thesis is related to the results of the qualitative evaluations. There is a wide range of exercises to investigate, or within those already explored it is possible to explore other contexts of use. Therefore, future works are needed for the exploration of sonifications' potential in other types of PA or to include extra challenges (e.g., adding weight in PA) and contexts of use (e.g., interventions or outdoors PA).

10.2.2. Exploring PA adherence in long-term studies for physically inactive people

In terms of PA adherence, in the qualitative study it was possible to implement mapping in SoniBand and test its long-term effects. The mappings increased body and movement awareness during PA and showed that they can be applied in an everyday context, specifically at home. However, this thesis focused only on a 2-week long home; it is possible that the mappings and SoniBand can facilitate PA adherence, but this has not been tested yet. Therefore, future works are needed to understand technology adoption and the potential effects on PA adherence of the movement-sound palettes. Interesting future research directions could address the effects of these metaphorical qualities and sound characteristics on longer exposure studies and evaluate the long-term adherence to PA in real-life contexts, in order to support people that are physically inactive. This also includes further explorations on mappings and sound characteristics to address barriers related to negative self-BP.

10.2.3. Articulate a set of recommendations for movement sonification in PA

This work started by exploring the potential effects of movement sonification in BP, and followed with both quantitative and qualitative studies, with the aim of elucidating in a nuanced way the impact of different metaphorical sounds and their characteristics on body and movement perception and PA; and to understand qualitatively the impact of sound in BP, as well as to identify similarities and differences in effects between inactive and active people. The goal with the qualitative studies was not to obtain generalizable results, but rather to capture the qualitative relation between certain sound qualities/characteristics and salient effects. In particular, there was interest in how the individual context (capabilities) and interpretation of the metaphorical sounds contributed to form different perceptions of people's own body and movement qualities. This thesis work articulated these relations as design considerations. Future works (qualitative and quantitative) are needed to continue exploring these and ultimately articulate a set of recommendations for movement sonification that can make a change in behavior for inactive people. This work is intended to provide the first step towards this, and the design considerations presented here are the first step towards it.

10.2.4. Extending sound feedback to collaborative environments

This thesis has focused on giving real-time sound feedback during PA to physically inactive adults individually. Therefore, the aspects of SoniBand and SoniShoes with their mappings only apply to sound feedback in a personal way. Although many of the aspects could be applied in another context, further research needs to be carried out to understand the sound effects in a collaborative environment. Some ideas emerge:

- Mirror effect: in some cases (gym or ballet) persons use a mirror to see if they are doing the exercise correctly during PA. To replicate this action, a person could do PA with another person, and using together the sound to perform the exercise in different ways:
    - Synchronizing the movements to get the "right" sound: this idea relates to the aim of providing movement information; as two people move their leg laterally independently, the sound could transmit desynchrony, while the sound would transmit synchrony if both perform the same movement together. Helping people to perform the movement together could in turn impact positively on their perceived body capabilities, such as feelings of coordination or movement fluidity.
    - Altered movement feedback when moving together: for example, the partners move together to produce real-time sound; it could be investigated whether receiving altered visual and sound feedback on their movement could affect people's body feelings, e.g., speed, agility, or proprioception, in a positive way. For instance, a wind sound could be used in the following manner: if both persons move simultaneously, the wind sound could make them feel they are going faster with a "light" sound. On the contrary, the sound could give them the impression of going slower with a strong wind sound given the sense of going against it, but at the same time build on feelings of strength. For instance, this was observed in

the "leg lift" movement (which is part of the strength program), were "Water", "Wind" and "Up" sound affected the feeling of strength, see Section 7.2.

- Playing: this idea emerges from the demo called "urban musical game" in which a group of persons are playing with a ball, passing it between them (https://frederic-bevilacqua.net/videos/). A virtual ball could produce sound when catching it and throwing it, and the sound could also signal the trajectory, increasing people's awareness of their performance. Future research could try different sound frequency content or metaphorical sounds to play with the perceived weight of the ball and investigate if this manipulation may change people's sense of effort, strength, and movement control.

The main aim of these ideas, besides looking at the efficiency of sound feedback when moving with more than one person, is to explore what bodily sensations arise when working in a collaborative environment, and to investigate how metaphorical sounds affect BP and movement behavior in a group of people.

10.2.5. Playful interactions and Physical activity: sound and visual feedback in virtual environments

This thesis has focused on giving real-time sound feedback during PA in a lab or indoor environments, with this last environment involving a mobile application which was limited in terms of calibration and selection of the sound. Therefore, the effects investigated with SoniBand and SoniShoes only apply to sound, without any other type of sensory feedback. Although many of the aspects could be applied in another context as in a collaborative environment as noted in the previous section, further research needs to be carried out to investigate the potential of using sound in combination with other types of feedback, such as visual feedback. To achieve this point of research, a person could do PA using multisensory feedback or in a virtual environment. Following this, two ideas emerge:

- Collaborative exergames to exercise collectively: [226] a research work that replaces circuit games of a kindergarten through the idea of "Hunting relics" in an exergame. The objective of the game is to combine collaboration mechanisms to do the task: working together (collaboration), taking turns, or dividing the task. For example, in one of the original games, two children must walk on their line on the floor side by side; while in the exergame children visualize a tight-rope instead of a line. In the exergame version, children were more "independent" receiving less prompts of the teachers and being more willing to collaborate. This research work provides visual feedback in a collaborative environment. Based on this, this thesis proposes to complement the performance related to PA through a story as hunting relics. For example, children could walk the tight-rope and at the same time they would listen to the sound of the wind as they cross the rope. Future works are needed to see whether the participants, when their movements are accompanied by the sound of the wind, perceive a resistance due to them feeling "walking against the wind", so they would feel more strength or feel their muscles are working harder. This possible use case leads us to wonder whether the participants, when receiving multisensory feedback (sound and visual) as opposed to unisensory feedback, could feel a change in their bodily sensations, or change their behavior, for example, whether the feeling of strength is greater with multisensory feedback than when receiving just one type of feedback.

- Combining movement sonification and Virtual Reality (VR): Following the previous idea, bringing this type of multisensory feedback to a virtual environment could help building the targeted bodily sensations. VR allows the creation of an artificial 3D environment with which the user can interact in real-time. VR can be divided into non-immersive VR and immersive VR: in immersive VR, differently from non-immersive VR, the user experiences the sensation of being inside the environment and being able to interact with its elements directly [227]. Besides the interest of using visual feedback in immersive VR in future work, it would be also interesting to understand the possibilities for changing body sensations by receiving feedback based on sonification on bodily movement inside of an immersive virtual environment [228]. For example, by transferring the "Hunting Relics" scenario to a virtual environment.

The two previous bullet points mentioned show the potential to work in facilitating PA through playful interactions. There are research works in the contexts of physical play [229]or physiotherapy rehabilitation [230], focused on designing playful interactions with the aim of influencing an explorative and enjoyable behavior [231]. An investigation on how virtual reality integrating sound feedback on body movement and allowing interaction in a playful way could support users in performing PA through alterations in BPs remains a challenge in the field of designing technology to address psychological barriers to PA.

10.3. Thesis summary

The research presented in this thesis is centered on developing technology to support PA in people with low levels of PA. This thesis focused on rethinking technology design for PA in physically inactive people by addressing psychological barriers related to BP. This research work made seven main contributions to the knowledge base and environment of the users by, (1) presenting a novel approach that combines movement sonification and bottom-up multisensory mechanisms to address psychological barriers related to BP; (2) providing a synthesis of psychological barriers to PA related to BP and strategies to address them; (3) providing a set of use cases for specific exercises in PA programs; (4) proposing a set of mappings for sensing technology with the potential to alter BP to facilitate PA in the home; (5) providing a set of design guidelines for sensory technologies for future work in this area; (6) proposing two wearable devices for movement sonification, towards promoting PA; and (7) impacting on society and psychological wellbeing of adults. Finally, several future works in this area were provided.

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APPENDICES

Appendix A. International Physical Activity Questionnaire (IPAQ)

URL for download: https://www.researchgate.net/project/IPAQ-short-form-Automatic-report

SUGERENCIA: utiliza la tecla del tabulador para desplazarte por las celdas editables

Informe automático del CUESTIONARIO INTERNACIONAL DE ACTIVIDAD FÍSICA

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Nombre y apelidos
Edad **años**
Peso **kilogramos**

CUESTIONARIO INTERNACIONAL DE ACTIVIDAD FISICA
PARA USO CON JÓVENES Y ADULTOS DE MEDIANA EDAD (15-69 años)

Estamos interesados en saber acerca de la clase de actividad física que la gente hace como parte de su vida diaria. Las preguntas se referirán acerca del tiempo que usted utilizó siendo físicamente activo(a) **en los últimos 7 días**. Por favor responda cada pregunta aún si usted no se considera una persona activa. Por favor piense en aquellas actividades que usted hace como parte del trabajo, en el jardín y en la casa, para ir de un sitio a otro, y en su tiempo libre de descanso, ejercicio o deporte.

Piense acerca de todas aquellas actividades **vigorosas** que usted realizó **en los últimos 7 días**. Actividades **vigorosas** son las que requieren un esfuerzo físico fuerte y le hacen respirar mucho más fuerte que lo normal. Piense solamente en esas actividades que usted hizo por lo menos 10 minutos continuos.

1. Durante los **últimos 7 días**, ¿Cuántos días realizó usted actividades físicas **vigorosas** como levantar objetos pesados, excavar, aeróbicos, o pedalear rápido en bicicleta?

0 días por semana   **Ninguna actividad física intensa. Pase a la pregunta 3**

2. ¿Cuánto tiempo en total usualmente le tomó realizar actividades físicas **vigorosas** en uno de esos días que las realizó?

0 ras por dia   0 minutos por dia   **No sabe/No está seguro(a)**

Piense acerca de todas aquellas actividades **moderadas** que usted realizo **en los últimos 7 días.** Actividades **moderadas** son aquellas que requieren un esfuerzo físico moderado y le hace respirar algo más fuerte que lo normal. Piense solamente en esas actividades que usted hizo por lo menos 10 minutos continuos.

3. Durante los **últimos 7 días**, ¿Cuántos días hizo usted actividades físicas moderadas tal como cargar objetos livianos, pedalear en bicicleta a paso regular, o jugar dobles de tenis? No incluya caminatas.

0 días por semana   **Ninguna actividad física moderada. Pase a la pregunta 5**

4. Usualmente, ¿Cuánto tiempo dedica usted en uno de esos días haciendo actividades físicas **moderadas**?

0 horas por día   0 minutos por día   **No sabe/No está seguro(a)**

Piense acerca del tiempo que usted dedicó a caminar en los **últimos 7 días**. Esto incluye trabajo en la casa, caminatas para ir de un sitio a otro, o cualquier otra caminata que usted hizo únicamente por recreación, deporte, ejercicio, o placer.

5. Durante los **últimos 7 días**, ¿Cuántos días caminó usted por al menos 10 minutos continuos?

0 días por semana   **Ninguna actividad física moderada. Pase a la pregunta 5**

6. Usualmente, ¿Cuánto tiempo gastó usted en uno de esos días **caminando**?

0 horas por día   0 minutos por día   **No sabe/No está seguro(a)**

La última pregunta se refiere al tiempo que usted permanenció **sentado(a)** en la semana en los **últimos 7 días**. Incluya el tiempo sentado(a) en el trabajo, la casa, estudiando, y en su tiempo libre. Esto puede incluir tiempo sentado(a) en un escritorio, visitando amigos(as), leyendo o permanecer sentado(a) o acostado(a) mirando television.

7. Durante los **últimos 7 días**, ¿Cuánto tiempo permaneció **sentado(a)** en un **día en la semana**?

0 horas por día   0 minutos por día   **No sabe/No está seguro(a)**

Este es el final del cuestionario, gracias por su participación.

Appendix B. International Fitness Scale (IFiS)

IFiS

Cuestionario de autoevaluación de la condición física

International FItness Scale

Es muy importante que contestes a estas preguntas tú solo, sin tener en cuenta las respuestas de otras personas. Tus respuestas sólo son útiles para el progreso de la ciencia. Por favor, contesta todas las preguntas y no las dejes en blanco. Y aún más importante, se sincero. Gracias por tú cooperación con la ciencia.

Por favor, piensa sobre tu nivel de condición física (comparado con tus amigos) y elige la opción más adecuada.

1. Mi condición física general es:

- ☐ Muy mala (1)
- ☐ Mala (2)
- ☐ Aceptable (3)
- ☐ Buena (4)
- ☐ Muy buena (5)

2. Mi condición física cardio-respiratoria (capacidad para hacer ejercicio, por ejemplo, correr durante mucho tiempo) es:

- ☐ Muy mala (1)
- ☐ Mala (2)
- ☐ Aceptable (3)
- ☐ Buena (4)
- ☐ Muy buena (5)

3. Mi fuerza muscular es:

- ☐ Muy mala (1)
- ☐ Mala (2)
- ☐ Aceptable (3)
- ☐ Buena (4)
- ☐ Muy buena (5)

4. Mi velocidad / agilidad es:

- ☐ Muy mala (1)
- ☐ Mala (2)
- ☐ Aceptable (3)
- ☐ Buena (4)
- ☐ Muy buena (5)

5. Mi flexibilidad es:

- ☐ Muy mala (1)
- ☐ Mala (2)
- ☐ Aceptable (3)
- ☐ Buena (4)
- ☐ Muy buena (5)

IFIS has been developed by the PROFITH research group, Granada, Spain. Versions of IFIS in different languages and for different age groups are available at: http://profith.ugr.es/IFIS IFIS was originally design and validated under the umbrella of the HELENA study, original reference: Ortega et al. The International Fitness Scale (IFIS): usefulness of self-reported fitness in youth. Int J Epidemiol 2011;40:701-1. IFIS has also been validated in adults: Ortega et al. Scand J Med Sci Sports, 2013;23:749-57; in children: Sanchez-Lopez et al. Scand J Med Sci Sports. 2015;25:543-51;and in women with fibromyalgia: Alvarez-Gallardo et al. Arch Phys Med Rehabil. 2016;97:395-404.

Appendix C. Information sheet and Consent form of the exploratory study

MagicShoes UNIVERSIDAD LOYOLA ANDALUCÍA Universidad Carlos III de Madrid

UNIÓN EUROPEA FONDO EUROPEO DE DESARROLLO REGIONAL

"Una manera de hacer Europa"

CARTA INFORMATIVA SOBRE EL ESTUDIO

Para la participación en este estudio, es necesario que lea atentamente la información que aparece a continuación.

<u>Información sobre el estudio</u>
Nos gustaría invitarle a participar en este proyecto de investigación desarrollado dentro del marco del proyecto *"ZAPATOS MÁGICOS: Mejora de los estilos de vida sedentarios mediante la alteración de la representación mental del cuerpo usando feedback sensorial"*, financiado por la Agencia Estatal de Investigación (AEI) y el Fondo Europeo de Desarrollo Regional (FEDER), dentro del Programa Estatal de I+D+i Orientado a los Retos de la Sociedad.

Solo debe participar si quiere. Elegir no tomar parte no tendrá ninguna repercusión para usted. Antes de decidir si desea participar, es importante que lea cuidadosamente la siguiente información y la discuta con otras personas si lo desea. Pregúntenos si hay algo que no está claro o si desea más información.

Con esta investigación queremos comprobar la influencia que tiene el sonido en la percepción del propio cuerpo y sus influencias en la actividad física de las personas. El objetivo final es desarrollar tecnología para ayudar a las personas a ser más activas físicamente.

Con este objetivo, aquellas personas que decidan participar serán entrevistadas sobre las necesidades y usos de dicha tecnología. Pediremos su opinión sobre el prototipo que hemos desarrollado. Podremos pedirle que haga ejercicio mientras usa sensores de movimiento. También podrá recibir retroalimentación multimodal, como sonido, al hacer estas actividades. Las actividades se registrarán utilizando los sensores y por grabación de audio. También le pediremos que complete cuestionarios demográficos o relacionados con sus sensaciones durante el estudio.

El estudio tendrá una duración máxima de una hora.

Los datos obtenidos a partir de las pruebas realizadas, (no aquellos datos personales), podrán ser publicados en revistas científicas, así como presentados a congresos, conferencias u otros eventos relacionados con la investigación.

Con su permiso, también nos gustaría utilizar extractos de las grabaciones de video y audio para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajo de tesis. Tenga en cuenta que estas presentaciones pueden ser registradas por personas sin nuestro conocimiento y mostradas en las redes sociales.

<u>¿Qué implica la participación?</u>
Por un lado, esperamos que las personas que decidan participar realicen las tareas teniendo en cuenta las indicaciones dadas.

La participación en este estudio es completamente voluntaria, pudiendo retirarse una vez haya firmado el consentimiento de participación, e incluso aunque ya haya comenzado la participación en el mismo.

Esta investigación no implica riesgo de ningún tipo para usted.

Todos los datos carácter personal, obtenidos en este estudio son confidenciales y se tratarán conforme al Reglamento General de Protección de Datos.

Si decide dar el consentimiento para que podamos contar usted, tiene que firmar el documento de Consentimiento Informado.

Si tiene cualquier duda, puede preguntarles a los investigadores, y si requiere información adicional, puede ponerse en contacto con la investigadora que dirige este estudio: Ana Tajadura Jiménez, en el teléfono 91 624 9415, o escribiendo a la dirección de correo electrónico: atajadur@inf.uc3m.es

¡Gracias!

CONSENTIMIENTO INFORMADO Y POR ESCRITO DEL PARTICIPANTE

Yo (Nombre y Apellidos), ……………………………………………………………………

- He leído el documento informativo que acompaña a este consentimiento.
- He podido hacer preguntas.
- He recibido suficiente información. He hablado con alguno de los investigadores de este estudio.
- Comprendo que mi participación es voluntaria y soy libre de participar o no en el estudio.
- Se me ha informado que todos los datos personales obtenidos en este estudio serán confidenciales y se tratarán conforme establece el Reglamento General de protección de Datos.
- Se me ha informado de que la información obtenida sólo se utilizará para los fines específicos del estudio.
- **Deseo** ser informado de mis datos de carácter personal que se obtengan en el curso de la investigación.

Si No

Para los siguientes puntos, marque con un círculo "Sí" o "No" e inicialice cada punto.

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores en este proyecto en estudios de investigación adicionales SÍ / NO

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores para demostrar la tecnología a las personas con inactividad física y al personal cínico SÍ / NO

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajos de tesis. Entiendo que estas presentaciones pueden ser registradas sin el conocimiento de los investigadores por los medios de comunicación u otros individuos / investigadores SI / NO

____ Estoy de acuerdo en que la grabación de video o audio sea utilizada en otros proyectos por miembros de este grupo de investigación SI NO

____Estoy de acuerdo en que la grabación de video o audio sea compartida con investigadores que no están involucrados en este proyecto SI NO

Comprendo que puedo retirarme del estudio:

- Cuando quiera
- Sin tener que dar explicaciones
- Sin que dicha decisión tenga ninguna repercusión

Presto libremente mi conformidad para participar en el estudio y ceder mis datos de carácter personal para su tratamiento en el desarrollo y ejecución del proyecto de investigación Magicshoes. Marcar con un aspa SI ( ) NO ( )

INFORMACIÓN BÁSICA SOBRE PROTECCIÓN DE DATOS. RESPONSABLE: Universidad Carlos III de Madrid. Delegado de Protección de Datos, ver información adicional. **CONSERVACIÓN**: Se suprimirán los datos de carácter personal una vez publicados los datos de investigación. Se recogerán datos de movimiento corporal (por ejemplo, forma de andar) y de señales fisiológicas (por ejemplo, señal cardíaca) que se conservarán indefinidamente por su interés para el desarrollo de proyectos de investigación similares. Asimismo se conservarán indefinidamente los datos cuyo titular haya prestado el consentimiento informado para su uso indefinido en el tiempo. **FINALIDAD:** Investigación sobre mejora de los estilos de vida sedentarios e inactivos mediante la alteración de la representación mental del cuerpo usando feedback sensorial. **LEGITIMACIÓN:** Consentimiento del interesado **DESTINATARIOS**: Investigadores participantes en el proyecto "MagicShoes" de la Universidad Loyola Andalucía, Universidad de Sevilla, Université Pierre et Marie Curie – FRANCIA, University College London - REINO UNIDO, Tallinn University - ESTONIA. **DERECHOS:** Acceder, rectificar y suprimir los datos, así como otros derechos en los términos que se indica en la información adicional. **INFORMACIÓN ADICIONAL:** Puede consultarse la información adicional detallada sobre protección de datos en nuestra página web http://www.uc3m.es/protecciondatos

Firma del/de la participante | Firma del/de la investigador/a informador/a

Nombre y apellidos:.................. | Nombre y apellidos: ....

Fecha: ...../...../..... | Fecha:...../...../.....

Appendix D. Information sheet and Consent form of the Study 1 - quantitative studies.

CARTA INFORMATIVA SOBRE EL ESTUDIO

Para la participación en este estudio, es necesario que lea atentamente la información que aparece a continuación.

<u>Información sobre el estudio</u>
Nos gustaría invitarle a participar en este proyecto de investigación desarrollado dentro del marco del proyecto *"ZAPATOS MÁGICOS: Mejora de los estilos de vida sedentarios mediante la alteración de la representación mental del cuerpo usando feedback sensorial"*, financiado por la Agencia Estatal de Investigación (AEI) y el Fondo Europeo de Desarrollo Regional (FEDER), dentro del Programa Estatal de I+D+i Orientado a los Retos de la Sociedad.

Solo debe participar si quiere. Elegir no tomar parte no tendrá ninguna repercusión para usted. Antes de decidir si desea participar, es importante que lea cuidadosamente la siguiente información y la discuta con otras personas si lo desea. Pregúntenos si hay algo que no está claro o si desea más información.

Con esta investigación queremos comprobar la influencia que tiene el sonido en la percepción del propio cuerpo y sus influencias en la actividad física de las personas. El objetivo final es desarrollar tecnología para ayudar a las personas a ser más activas físicamente.

Con este objetivo, les pediremos que haga dos tipos de ejercicios, caminar y estiramiento de muslo, mientras usa sensores de movimiento y llevan una pulsera con biosensores. También podrá escuchar sonidos, al hacer estas actividades. Las actividades se registrarán utilizando los sensores y por grabación de video / audio. También le pediremos que complete cuestionarios demográficos o relacionados con sus sensaciones durante el estudio. Además, tomaremos medidas de su cuerpo midiendo su altura, y pesándole con una bascula.

El estudio tendrá una duración máxima de una hora.

Los datos obtenidos a partir de las pruebas realizadas, (no aquellos datos personales), podrán ser publicados en revistas científicas así como presentados a congresos, conferencias u otros eventos relacionados con la investigación.

Con su permiso, también nos gustaría utilizar extractos de las grabaciones de video y audio para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajo de tesis. Tenga en cuenta que estas presentaciones pueden ser registradas por personas sin nuestro conocimiento y mostradas en las redes sociales.

<u>¿Qué implica la participación?</u>
Por un lado, esperamos que las personas que decidan participar realicen las tareas teniendo en cuenta las indicaciones dadas.

Versión 1.0 5/03/2019

La participación en este estudio es completamente voluntaria, pudiendo retirarse una vez haya firmado el consentimiento de participación, e incluso aunque ya haya comenzado la participación en el mismo.

Recibirá una compensación económica de 10 euros por su participación.

Esta investigación no implica riesgo de ningún tipo para usted.

Todos los datos carácter personal, obtenidos en este estudio son confidenciales y se tratarán conforme al Reglamento General de Protección de Datos.

Si decide dar el consentimiento para que podamos contar usted, tiene que firmar el documento de Consentimiento Informado.

Si tiene cualquier duda, puede preguntarles a los investigadores, y si requiere información adicional, puede ponerse en contacto con la investigadora que dirige este estudio: Ana Tajadura Jiménez, en el teléfono 91 624 9415, o escribiendo a la dirección de correo electrónico: atajadur@inf.uc3m.es

¡Gracias!

CONSENTIMIENTO INFORMADO Y POR ESCRITO DEL PARTICIPANTE

Yo (Nombre y Apellidos), ...

- He leído el documento informativo que acompaña a este consentimiento.
- He podido hacer preguntas.
- He recibido suficiente información. He hablado con alguno de los investigadores de este estudio.
- Comprendo que mi participación es voluntaria y soy libre de participar o no en el estudio.
- Se me ha informado que todos los datos personales obtenidos en este estudio serán confidenciales y se tratarán conforme establece el Reglamento General de protección de Datos.
- Se me ha informado de que la información obtenida sólo se utilizará para los fines específicos del estudio.
- **Deseo** ser informado de mis datos de carácter personal que se obtengan en el curso de la investigación.

Si No

Para los siguientes puntos, marque con un círculo "Sí" o "No" e inicialice cada punto.

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores en este proyecto en estudios de investigación adicionales SÍ / NO

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores para demostrar la tecnología a las personas con inactividad física y al personal clínico SÍ / NO

____Estoy de acuerdo en que la grabación de video o audio sea utilizada por los investigadores para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajos de tesis. Entiendo que estas presentaciones pueden ser registradas sin el conocimiento de los investigadores por los medios de comunicación u otros individuos / investigadores SI / NO

____ Estoy de acuerdo en que la grabación de video o audio sea utilizada en otros proyectos por miembros de este grupo de investigación SI NO

____Estoy de acuerdo en que la grabación de video o audio sea compartida con investigadores que no están involucrados en este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de otros proyectos SI NO

Comprendo que puedo retirarme del estudio:

- Cuando quiera
- Sin tener que dar explicaciones
- Sin que dicha decisión tenga ninguna repercusión

Presto libremente mi conformidad para participar en el estudio y ceder mis datos de carácter personal para su tratamiento en el desarrollo y ejecución del proyecto de investigación Magicshoes. Marcar con un aspa SI ( ) NO ( )

INFORMACIÓN BÁSICA SOBRE PROTECCIÓN DE DATOS. RESPONSABLE: Universidad Carlos III de Madrid. Delegado de Protección de Datos, ver información adicional. **CONSERVACIÓN**: Se suprimirán los datos de carácter personal una vez publicados los datos de investigación. Se recogerán datos de movimiento corporal (por ejemplo, forma de andar) y de señales fisiológicas (por ejemplo, señal cardíaca) que se conservarán indefinidamente por su interés para el desarrollo de proyectos de investigación similares. Asimismo se conservarán indefinidamente los datos cuyo titular haya prestado el consentimiento informado para su uso indefinido en el tiempo. **FINALIDAD:** Investigación sobre mejora de los estilos de vida sedentarios e inactivos mediante la alteración de la representación mental del cuerpo usando feedback sensorial. **LEGITIMACIÓN:** Consentimiento del interesado **DESTINATARIOS**: Investigadores participantes en el proyecto "MagicShoes" de la Universidad Loyola Andalucía, Universidad de Sevilla, Université Pierre et Marie Curie – FRANCIA, University College London - REINO UNIDO, Tallinn University - ESTONIA. **DERECHOS:** Acceder, rectificar y suprimir los datos, así como otros derechos en los términos que se indica en la información adicional. **INFORMACIÓN ADICIONAL:** Puede consultarse la información adicional detallada sobre protección de datos en nuestra página web http://www.uc3m.es/protecciondatos

Firma del/de la participante | Firma del/de la investigador/a informador/a

Nombre y apellidos:………………. | Nombre y apellidos: …………..

Fecha: …../…../….. | Fecha:…../…../…..

Appendix E. Questionnaire 1 (sound conditions) of the Study 1 - quantitative studies

Con sonido - Sensación corporal

Por favor, tacha con una cruz el muñeco que crees que mejor expresa como te sentiste durante el
ejercicio. Elige un muñeco en cada una de las dos figuras de debajo.

1. Número del participante

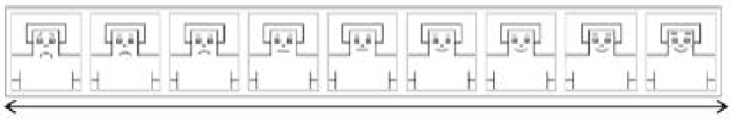
____

2. Condición

Marca solo un óvalo.

- ◯ constant
- ◯ Ascending
- ◯ Descending

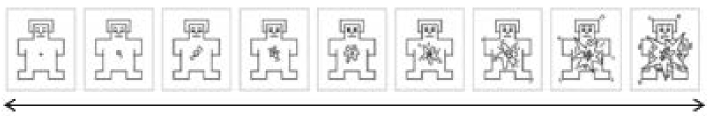
En relación con el sonido me sentia...



3\.

Marca solo un óvalo.

	1	2	3	4	5	6	7	8	9	
Infeliz-Molesto-Negativo	◯	◯	◯	◯	◯	◯	◯	◯	◯	Feliz-Satisfecho-Positivo



4\.

Marca solo un óvalo.

	1	2	3	4	5	6	7	8	9	
Relajado-Tranquilo-Aburrido	◯	◯	◯	◯	◯	◯	◯	◯	◯	Estimulado-Excitado-Nervioso

El número que crees que mejor expresa como te sentiste de acuerdo con las siguientes oraciones.

5. Mientras hacia el ejercicio con el sonido me sentía...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Ligero	◯	◯	◯	◯	◯	◯	◯	Pesado

6. Mientras hacia el ejercicio con el sonido me sentía en... con mis movimientos.

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descontrol	◯	◯	◯	◯	◯	◯	◯	Control

7. Mientras hacia el ejercicio con el sonido sentía mi corazón/respiración...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Desacelerado	◯	◯	◯	◯	◯	◯	◯	Acelerado

8. Mientras hacia el ejercicio con el sonido me sentía...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Débil	◯	◯	◯	◯	◯	◯	◯	Fuerte

9. Mientras hacia el ejercicio con el sonido me sentía...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Lento	◯	◯	◯	◯	◯	◯	◯	Rápido

10. Mientras hacia el ejercicio con el sonido me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada ágil	◯	◯	◯	◯	◯	◯	◯	Ágil

11. Mientras hacia el ejercicio con el sonido me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada flexible	◯	◯	◯	◯	◯	◯	◯	Flexible

12. Mientras hacia el ejercicio con el sonido me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada cansado	◯	◯	◯	◯	◯	◯	◯	Cansado

13. El ejercicio con el sonido fue...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Fácil	◯	◯	◯	◯	◯	◯	◯	Difícil

14. Mientras hacia el ejercicio con el sonido sentia que mis movimientos eran...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descoordinados	◯	◯	◯	◯	◯	◯	◯	Coordinados

15. Mientras hacia el ejercicio con el sonido sentia que mis movimientos fueron...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada fluidos	◯	◯	◯	◯	◯	◯	◯	Fluidos

Appendix F. Questionnaire 1 (no sound) of the Study 1 - quantitative studies.

Sin sonido - Sensación corporal

Por favor, tacha con una cruz el muñeco que crees que mejor expresa como te sentiste durante el
ejercicio. Elige un muñeco en cada una de las dos figuras de debajo.

1. Número del participante

2. Ejercicio

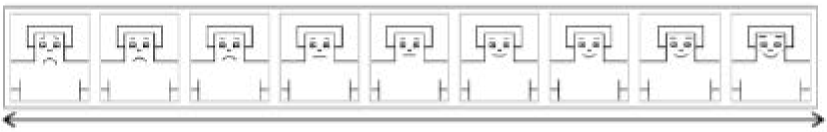
   Marca solo un óvalo.

   ◯ Caminar
   ◯ estirar

3. Condición

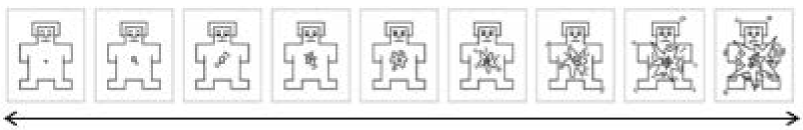
   Marca solo un óvalo.

   ◯ Sin sonido



4. *Marca solo un óvalo.*

	1	2	3	4	5	6	7	8	9	
Infeliz-Molesto-Negativo	◯	◯	◯	◯	◯	◯	◯	◯	◯	Feliz-Satisfecho-Positivo



5.

Marca solo un óvalo.

	1	2	3	4	5	6	7	8	9	
Relajado-Tranquilo-Aburrido	◯	◯	◯	◯	◯	◯	◯	◯	◯	Estimulado-Excitado-Nervioso

El número que crees que mejor expresa como te sentiste de acuerdo con las siguientes oraciones.

6. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Ligero	◯	◯	◯	◯	◯	◯	◯	Pesado

7. Mientras hacia el ejercicio me sentia en... con mis movimientos.

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descontrol	◯	◯	◯	◯	◯	◯	◯	Control

8. Mientras hacia el ejercicio sentia mi corazón/respiración...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Desacelerado	◯	◯	◯	◯	◯	◯	◯	Acelerado

9. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Débil	◯	◯	◯	◯	◯	◯	◯	Fuerte

10. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Lento	◯	◯	◯	◯	◯	◯	◯	Rápido

11. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada ágil	◯	◯	◯	◯	◯	◯	◯	Ágil

12. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada flexible	◯	◯	◯	◯	◯	◯	◯	Flexible

13. Mientras hacia el ejercicio me sentia...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada cansado	◯	◯	◯	◯	◯	◯	◯	Cansado

14. El ejercicio fue...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Fácil	◯	◯	◯	◯	◯	◯	◯	Difícil

15. Mientras hacia el ejercicio sentia que mis movimientos eran...

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descoordinados	◯	◯	◯	◯	◯	◯	◯	Coordinados

Appendix G. Information sheet and Consent form of the Study 2 - quantitative studies.

Information Sheet for Participants in Research Studies

You will be given a copy of this information sheet.

Title of Project:	**Sonification for gym activity: Bodily feelings**
This study has been approved by the UCL Research Ethics Committee as Project ID Number:	**UCLIC/1516/003/StaffBerthouze/Newbold**
Name, Address and Contact Details of Investigators:	Dr Nadia Bianchi-Berthouze UCL Interaction Centre 66 - 72 Gower Street, London WC1E 6EA United Kingdom 020 3108 7067

We would like to invite you to participate in this research project, carried out in collaboration with Dr Ana Tajadura-Jiménez based at the Computer Science Department, Universidad Carlos III de Madrid, Spain. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or you would like more information.

The aim of this project is to develop technology to help people doing physical activity by using sound stimulation. At first, we will ask you to fill up a questionnaire. Then, we will ask you to do a simple exercise -lift a leg- while wearing headphones and a pair of sonic sandals which contain movement sensors. The tasks will be repeated with different sounds. Between each sound condition we will ask you to fill up a questionnaire. Another questionnaire will be provided at the end of all conditions.

The experiment does not involve any risk for you. The whole study lasts around 60 minutes. You can choose to have 1 academic credit or to participate in a raffle of 50 pounds for taking part in the study.

It is up to you to decide whether or not to take part. If you choose not to participate, you won't incur any penalties or lose any benefits to which you might have been entitled. However, if you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Even after agreeing to take part, you can still withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection rules. Anonymous movement data from the movement sensors, and voice recordings will be stored in a computer. Researchers working with me will analyze the data collected. Anonymous data will be shared with Dr Ana Tajadura-Jiménez and her team at Universidad Carlos III de Madrid, Spain (see website http://dei.inf.uc3m.es/dei_web/dei_web/?page=people)

Informed Consent Form for Participants in Research Studies

(This form is to be completed independently by the participant after reading the Information Sheet and/or having listened to an explanation about the research.)

Title of Project: **Sonification for gym activity: Bodily feelings**

This study has been approved by the UCL Research Ethics Committee as Project ID Number: **UCLIC/1516/003/StaffBerthouze/Newbold**

Participant's Statement

I ....

agree that I have

- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study; and
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that I must not take part if I am not physically able to do the tasks
- Given this I am happy to engage in mild physical activity and wear non-intrusive movement sensors

I understand that:

- anonymous movement data from the movement sensors and voice recordings will be stored in a computer.
- anonymus data will be shared with Dr Ana Tajadura-Jiménez, collaborator in this research project, based at Universidad Carlos III de Madrid, Spain.

For the following please circle "Yes" or "No" and initial the point.

_____ I am freely agreeing to participate in the study and consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection rules. YES / NO

_____ I am freely agreeing to the transfer of anonymous data to Dr Ana Tajadura-Jiménez, collaborator in this research project and based at Carlos III University of Madrid, Spain, for their treatment in the development and execution of this research project. YES / NO

_____ I agree to be contacted in the future by UCL researchers who would like to invite me to participate in follow-up studies YES / NO

BASIC INFORMATION ON DATA PROTECTION. RESPONSIBLE: University College London. CONSERVATION: Personal data will be deleted once the research data has been published. Body movement data will be collected and kept indefinitely for their interest in the development of similar research projects. Likewise, the data whose holder has given the informed consent for its use will be kept indefinitely. PURPOSE: Research on the improvement of sedentary and inactive lifestyles through the alteration of the mental representation of the body using sensory feedback LEGITIMACY: Consent of the person of interest. RECIPIENTS: Nadia Bianchi-Berthouze, University College London; Ana Tajadura-Jiménez, Universidad Carlos III de Madrid; Patricia Rick Rivera, Universidad Loyola Andalucía.

Signed: Date:

Investigator's Statement

I ……………………………………………………………………….

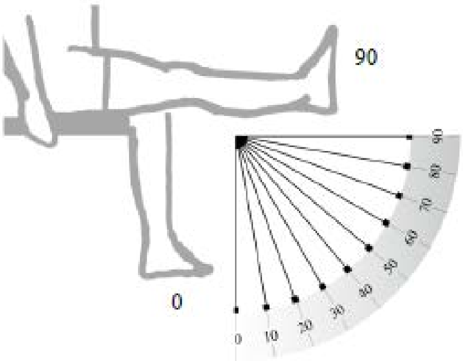
confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date:

Appendix H. Questionnaire 1 (sound conditions) of the Study 2 - quantitative studies

Questionnaire____ Sound condition____number__
P___

How much did you raise your leg? Point in the scheme below.



How easy was to raise the leg at that level?

1	2	3	4	5	6	7
Very difficult			Neither easy/ nor difficult			Very easy

Did you feel the sound was linked to any sport?

No

Yes → To which one? ……………………………………………………

What does this sound remind you of? ……………………………………………………

Please circle the number you think that best expresses your level of agreement with the sentences below.

Doing the exercise with this sound makes me think of myself…

…as a sportsperson

1	2	3	4	5	6	7	8	9
Totally agree				Neither agree/ nor disagree				Totally disagree

…as someone who is very concerned with sport issues

1	2	3	4	5	6	7	8	9
Totally agree				Neither agree/ nor disagree				Totally disagree

Please circle the number you think that best expresses your level of agreement with the sentences below.

As I was doing the exercise I felt …

1	2	3	4	5	6	7
Weak			Neutral			Strong

As I was doing the exercise I felt ...

1	2	3	4	5	6	7

Slow — Neutral — Quick

As I was doing the exercise I felt ...

1	2	3	4	5	6	7

Not agile — Neutral — Agile

As I was doing the exercise I felt my muscle was...

1	2	3	4	5	6	7

Not working at all — Neutral — Working hard

As I was doing the exercise I felt capable/incapable of completing the exercise ...

1	2	3	4	5	6	7

Incapable — Neutral — Capable

As I was doing the exercise I felt I could not tell/could tell exactly were my foot was...

1	2	3	4	5	6	7

Could not tell — Neutral — Could tell

As I was doing the exercise my leg felt...

1	2	3	4	5	6	7

Light — Neutral — Heavy

As I was doing the exercise I felt my movements were...

1	2	3	4	5	6	7

Not fluid — Neutral — Fluid

The exercise was...

1	2	3	4	5	6	7

Effortless — Neutral — Challenging

The sound I heard was...

1	2	3	4	5	6	7

Not produced by me — Neutral — Produced by me

The sound I heard was...

1	2	3	4	5	6	7

Uncomfortable — Neutral — Comfortable

The sound I heard..

1	2	3	4	5	6	7

Did not motivate me to do exercise — Neutral — Motivated me to do exercise

I found doing this exercise was...

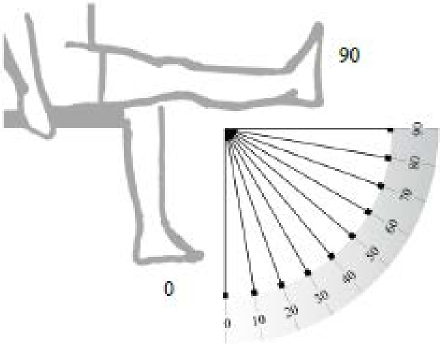
1	2	3	4	5	6	7

Strange, Artificial — Neutral — Natural

Appendix I. Questionnaire 1 (no sound) of the Study 2 - quantitative studies

Questionnaire____ Sound condition____number__
P___

How much did you raise your leg? Point in the scheme below.



How easy was to raise the leg at that level?

1	2	3	4	5	6	7
Very difficult			Neither easy/ nor difficult			Very easy

Please circle the number you think that best expresses your level of agreement with the sentences below.

Doing the exercise with no sound makes me think of myself...

...as a sportsperson

1	2	3	4	5	6	7	8	9
Totally agree				Neither agree/ nor disagree				Totally disagree

...as someone who is very concerned with sport issues

1	2	3	4	5	6	7	8	9
Totally agree				Neither agree/ nor disagree				Totally disagree

Please circle the number you think that best expresses your level of agreement with the sentences below.

As I was doing the exercise I felt ...

1	2	3	4	5	6	7
Weak			Neutral			Strong

As I was doing the exercise I felt ...

1	2	3	4	5	6	7
Slow			Neutral			Quick

As I was doing the exercise I felt ...

1	2	3	4	5	6	7
Not agile			Neutral			Agile

As I was doing the exercise I felt my muscle was...

1	2	3	4	5	6	7
Not working at all			Neutral			Working hard

As I was doing the exercise I felt capable/incapable of completing the exercise ...

1	2	3	4	5	6	7
Incapable			Neutral			Capable

As I was doing the exercise I felt I could not tell/could tell exactly were my foot was...

1	2	3	4	5	6	7
Could not tell			Neutral			Could tell

As I was doing the exercise my leg felt...

1	2	3	4	5	6	7
Light			Neutral			Heavy

As I was doing the exercise I felt my movements were...

1	2	3	4	5	6	7
Not fluid			Neutral			Fluid

The exercise was...

1	2	3	4	5	6	7
Effortless			Neutral			Challenging

I found doing this exercise was...

1	2	3	4	5	6	7
Strange, Artificial			Neutral			Natural

Appendix J. Questionnaire 2 of the Study 2 - quantitative studies

Questionnaire F

P___

Now we would like you to compare the different sound conditions that you have heard. Please order them in the Likert scale according to the sentences below. Identify each sound condition with a number defined by the order in which the sound has been presented (from 1 to 5).

Doing the exercise made me think of myself...

...as a sportsperson

1	2	3	4	5	6	7	8	9
Totally agree				Neither agree/ nor disagree				Totally disagree

During the experience I felt...

1	2	3	4	5	6	7
Weak			Neutral			Strong

During the experience I felt I was...

1	2	3	4	5	6	7
Not building muscle			Neutral			Building muscle

During the experience I felt capable/incapable of completing the exercise ...

1	2	3	4	5	6	7
Incapable			Neutral			Capable

The exercise was...

1	2	3	4	5	6	7
Effortless			Neutral			Challenging

The sound I heard..

1	2	3	4	5	6	7
Did not motivate me to do exercise			Neutral			Motivate me to do exercise

Demographic questions

How old are you?...........

What is your approximate weight?.........

What is your approximate height?..........

What is your sex? Circle the correct one: Female Male Other

Appendix K. Information sheet and Consent form of the study 3 (Experiment 1 & 2) in quantitative studies.

CARTA INFORMATIVA SOBRE EL ESTUDIO

Para la participación en este estudio, es necesario que lea atentamente la información que aparece a continuación.

Información sobre el estudio

Nos gustaría invitarle a participar en este proyecto de investigación desarrollado dentro del marco del proyecto *"ZAPATOS MÁGICOS: Mejora de los estilos de vida sedentarios mediante la alteración de la representación mental del cuerpo usando feedback sensorial"*, financiado por la Agencia Estatal de Investigación (AEI) y el Fondo Europeo de Desarrollo Regional (FEDER), dentro del Programa Estatal de I+D+i Orientado a los Retos de la Sociedad.

Solo debe participar si quiere. Elegir no tomar parte no tendrá ninguna repercusión para usted. Antes de decidir si desea participar, es importante que lea cuidadosamente la siguiente información y la discuta con otras personas si lo desea. Pregúntenos si hay algo que no está claro o si desea más información.

Con esta investigación queremos comprobar la influencia que tiene el sonido en la percepción del propio cuerpo de las personas. El objetivo final es desarrollar tecnología para ayudar a las personas a ser más activas físicamente.

Con este objetivo, le facilitaremos un dispositivo con sensores de movimiento y sonido integrado, y le pediremos que realice un movimiento lateral de brazo para alcanzar dos posiciones diferentes (70 y 120 grados). Podrá escuchar diferentes sonidos, al hacer esta actividad. Los movimientos se registrarán utilizando los sensores. También le pediremos que complete cuestionarios.

El estudio tendrá una duración de una hora.

Los datos obtenidos a partir de las pruebas realizadas (no aquellos datos personales), podrán ser publicados en revistas científicas, así como presentados a congresos, conferencias u otros eventos relacionados con la investigación.

¿Qué implica la participación?

Por un lado, esperamos que las personas que decidan participar realicen las tareas teniendo en cuenta las indicaciones dadas.

La participación en este estudio es completamente voluntaria, pudiendo retirarse una vez haya firmado el consentimiento de participación, e incluso aunque ya haya comenzado la participación en el mismo.

Recibirá una compensación económica de 10 euros por su participación.

Esta investigación no implica riesgo de ningún tipo para usted.

Todos los datos de carácter personal, obtenidos en este estudio son confidenciales y se tratarán conforme al Reglamento General de Protección de Datos.

Si decide dar el consentimiento para que podamos contar usted, tiene que firmar el documento de Consentimiento Informado.

Si tiene cualquier duda, puede preguntarles a los investigadores, y si requiere información adicional, puede ponerse en contacto con la investigadora que dirige este estudio: Ana Tajadura Jiménez, en el teléfono 91 624 9415, o escribiendo a la dirección de correo electrónico: atajadur@inf.uc3m.es

¡Gracias!

CONSENTIMIENTO INFORMADO Y POR ESCRITO DEL PARTICIPANTE

Yo (Nombre y Apellidos), ...

- He leído el documento informativo que acompaña a este consentimiento.
- He podido hacer preguntas.
- He recibido suficiente información. He hablado con alguno de los investigadores de este estudio.
- Comprendo que mi participación es voluntaria y soy libre de participar o no en el estudio.
- Se me ha informado que todos los datos personales obtenidos en este estudio serán confidenciales y se tratarán conforme establece el Reglamento General de protección de Datos.
- Se me ha informado de que la información obtenida sólo se utilizará para los fines específicos del estudio.
- Deseo ser informado de mis datos de carácter personal que se obtengan en el curso de la investigación.

Si No

Para los siguientes puntos, marque con un círculo "Sí" o "No" e inicialice cada punto.

____Estoy de acuerdo en que la grabación de audio sea utilizada por los investigadores en este proyecto en estudios de investigación adicionales SI / NO

____ Estoy de acuerdo en que la grabación de audio sea utilizada en otros proyectos por miembros de este grupo de investigación SI / NO

____Estoy de acuerdo en que la grabación de audio sea compartida con investigadores que no están involucrados en este proyecto SI / NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de este proyecto SI / NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de otros proyectos SI / NO

Comprendo que puedo retirarme del estudio:

- Cuando quiera
- Sin tener que dar explicaciones
- Sin que dicha decisión tenga ninguna repercusión

Presto libremente mi conformidad para participar en el estudio y ceder mis datos de carácter personal para su tratamiento en el desarrollo y ejecución del proyecto de investigación Magicshoes. Marcar con un aspa SI ( ) NO ( )

INFORMACIÓN BÁSICA SOBRE PROTECCIÓN DE DATOS. RESPONSABLE: Universidad Carlos III de Madrid. Delegado de Protección de Datos, ver información adicional. **CONSERVACIÓN**: Se suprimirán los datos de carácter personal una vez publicados los datos de investigación. Se recogerán datos de movimiento corporal (por ejemplo, forma de andar) y de señales fisiológicas (por ejemplo, señal cardíaca) que se conservarán indefinidamente por su interés para el desarrollo de proyectos de investigación similares. Asimismo se conservarán indefinidamente los datos cuyo titular haya prestado el consentimiento informado para su uso indefinido en el tiempo. **FINALIDAD:** Investigación sobre mejora de los estilos de vida sedentarios e inactivos mediante la alteración de la representación mental del cuerpo usando feedback sensorial. **LEGITIMACIÓN:** Consentimiento del interesado **DESTINATARIOS**: Investigadores participantes en el proyecto "MagicShoes" de la Universidad Loyola Andalucía, Universidad de Sevilla, Université Pierre et Marie Curie – FRANCIA, University College London - REINO UNIDO, Tallinn University - ESTONIA. **DERECHOS:** Acceder, rectificar y suprimir los datos, así como otros derechos en los términos que se indica en la información adicional. **INFORMACIÓN ADICIONAL:** Puede consultarse la información adicional detallada sobre protección de datos en nuestra página web http://www.uc3m.es/protecciondatos

Firma del/de la participante | Firma del/de la investigador/a informador/a

Nombre y apellidos:.................... | Nombre y apellidos: ....

Fecha: ...../...../..... | Fecha:...../...../.....

Appendix L. Questionnaire of the Study 3, Experiment 1 - quantitative studies.

Estudio 1

Sensación corporal

*Obligatorio

1. Número del participante

____

2. Condición

Marca solo un óvalo.

- ( ) Condition A
- ( ) Condition D
- ( ) Condition C

A continuación, indica el número que crees que mejor expresa como te sentiste al realizar el ejercicio con el sonido que acabas de escuchar

3. Estoy... de que mi brazo estaba en la posición 1 *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Muy inseguro	( )	( )	( )	( )	( )	( )	( )	Muy seguro

4. Estoy... de que mi brazo estaba en la posición 2 *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Muy inseguro	( )	( )	( )	( )	( )	( )	( )	Muy seguro

Sensación corporal - Parte 2

A continuación, indica el número que crees que mejor expresa como te sentiste al realizar el ejercicio con el sonido que acabas de escuchar

5. Mientras hacia el ejercicio con el sonido me sentia... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Ligero	◯	◯	◯	◯	◯	◯	◯	Pesado

6. Mientras hacia el ejercicio con el sonido me sentia en completo... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descontrol de mis movimientos	◯	◯	◯	◯	◯	◯	◯	Control de mis movimientos

7. Mientras hacia el ejercicio con el sonido me sentia... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Lento	◯	◯	◯	◯	◯	◯	◯	Rápido

8. Mientras hacia el ejercicio con el sonido me sentia... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada cansado	◯	◯	◯	◯	◯	◯	◯	Cansado

9. Con este sonido el ejercicio me resultó... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Fácil	◯	◯	◯	◯	◯	◯	◯	Difícil

10. Con este sonido me sentía ... de hacer el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Incapaz	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Capaz

11. Al escuchar este sonido, sentía que el sonido... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
No lo producía yo	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Lo producía yo

12. Escuchar este sonido ... a realizar el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
No me motivaba	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Me motivaba

13. Al escuchar este sonido me resulta ... hacer el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Incómodo	⬭	⬭	⬭	⬭	⬭	⬭	⬭	Cómodo

Appendix M. Questionnaire of the Study 3, Experiment 2 - quantitative studies.

Estudio2

Sensación corporal - Parte 1

*Obligatorio

1. Número del participante

____

2. Condición

Marca solo un óvalo.

- ConditionAA(AscendingTone)
- ConditionAD(AscendingNote)
- ConditionFA(DescendingTone)
- ConditionFD(DescendingNote)

A continuación, indica el número que crees que mejor expresa como te sentiste al realizar el ejercicio con el sonido que acabas de escuchar

3. Estoy... de que mi brazo estaba en la posición 1 *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Muy inseguro	◯	◯	◯	◯	◯	◯	◯	Muy seguro

4. Estoy... de que mi brazo estaba en la posición 2 *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Muy inseguro	◯	◯	◯	◯	◯	◯	◯	Muy seguro

Sensación corporal - Parte 2

A continuación, indica el número que crees que mejor expresa como te sentiste al realizar el ejercicio con el sonido que acabas de escuchar

	1	2	3	4	5	6	7	
Ligero	◯	◯	◯	◯	◯	◯	◯	Pesado

6. Mientras hacía el ejercicio con el sonido me sentía en completo... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Descontrol de mis movimientos	◯	◯	◯	◯	◯	◯	◯	Control de mis movimientos

7. Mientras hacía el ejercicio con el sonido me sentía... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Lento	◯	◯	◯	◯	◯	◯	◯	Rápido

8. Mientras hacía el ejercicio con el sonido me sentía... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Nada cansado	◯	◯	◯	◯	◯	◯	◯	Cansado

9. Con este sonido el ejercicio me resultó... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Fácil	◯	◯	◯	◯	◯	◯	◯	Difícil

10. Con este sonido me sentía ... de hacer el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Incapaz	◯	◯	◯	◯	◯	◯	◯	Capaz

11. Al escuchar este sonido, sentía que el sonido... *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
No lo producía yo	◯	◯	◯	◯	◯	◯	◯	Lo producía yo

12. Escuchar este sonido ... a realizar el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
No me motivaba	◯	◯	◯	◯	◯	◯	◯	Me motivaba

13. Al escuchar este sonido me resulta ... hacer el ejercicio *

Marca solo un óvalo.

	1	2	3	4	5	6	7	
Incómodo	◯	◯	◯	◯	◯	◯	◯	Cómodo

Appendix N. Information sheet and Consent form of the study 3 (Experiment 3) in Quantitative studies.

UCL INTERACTION CENTRE
RESEARCH•CONSULTANCY•SEMINARS•COURSES

UCL Interaction Centre
2nd floor, 66 – 72 Gower St
London WC1E 6EA

UCL

INFORMATION SHEET FOR REMOTE PARTICIPANT

Project Title: EnTimeMent

Department: University College London Interaction Centre

Researcher:

Principal Researcher:

Please note that the phones attached to the numbers above are not manned during the period of the COVID-19 lockdown. During this period, kindly use the emails provided instead.

1. **Invitation Paragraph**
   You are being invited to take part in a research project. Before you decide whether to take part, it is important for you to understand why the research is being done and what participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

2. **What is the project's purpose?**
   The project extends previous studies where we developed scientific knowledge and technological tools toward supporting engagement in everyday physical activity for people with chronic pain and engagement in fitness activities for the general population. In the current project, we aim to further advance understanding of human movement and develop sound/music systems that are tailored to facilitate movement. This is part of a larger project called H2020 FET EnTimeMent (https://entimement.dibris.unige.it) funded by the European community and aimed at developing new movement sensing technologies that better define movement at different time scales.

3. **Why have I been chosen?**
   We are asking people from the general population to volunteer for this study, if they are at least 18 years of age.

4. **Do I have to take part?**
   It is up to you to decide whether or not to take part. If you do decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. You can withdraw from the study at any time and without giving a reason. You will not in any way be penalised for withdrawing from the study.
   You can additionally withdraw data that you have provided to us, up till 14 days after the last data you send to us, without giving a reason. To withdraw from the study or withdraw your data,

UCLIC Approved Version No.: 1.0c Approved Date: 29 May 2019 UCL REC Project ID.: 5095/001 you should contact the researcher, using the contact details at the top of this information sheet. We will no longer use data that you withdraw if it is withdrawn no more than 14 days after the last data you send to us.

If you choose to withdraw from the study, you will be asked to revoke your original consent by signing a consent change form.

5. **What will happen to me if I take part?**

You will be asked to complete questionnaires about your physical activities and your experiences relating to these. You may also be asked to think aloud your thoughts or feelings or ideas.

You will additionally be asked to use a software application on your smartphone that will capture and record your body movements while you perform low-intensity exercises (e.g. squat or arm raises). The extent to which you do each exercise will be up to you, and you would be able to take breaks when you feel the need to.

Sound feedback representing your movement may be provided during the performance of these activities. The sound feedback you get may be tailored to your movements (tracked by sensors in your phone).

We will further have a brief discussion with you about your movements, related experiences, and/or your experiences with the feedback we provide.

6. **Will I be recorded and how will the recorded media be used?**

Your Name and Contact Information - NO ONE outside of our research team will be allowed access to any written or verbal information which can be used to personally identify you that you provide in your communication with us and in giving your consent.

Your Responses

What we will record:

a. Smartphone sensor data - You will be provided with an application to install onto your smartphone to record your movement using inbuilt sensors. The data will be saved to a secure server storage. You will not be identifiable from the sensor data in the storage as these data simply record the amount of movement made by your body (e.g., amount of bending of the leg).
b. Textual data - Your responses to our questions in text form will be recorded in digital format either as online forms or other electronic documents, e.g. pdf forms.
c. Video/Audio Experimental data - Our experiment with you will be done remotely via a telephone call or secure video/audio conferencing. For accurate detailing, the procedure will be video- or audio-recorded. Should any videos recorded contain someone who is not you or indecent content, we will edit out the third party and the indecent content before further processing of the data. However, we ask you if possible to avoid people enter in the video. If you prefer to have someone with you (adult only) during the recording, the person will be asked to sign a consent form too.

All of the video, and audio data will be stored securely and only accessed by members of our research team.

How we will use what we record: The data we record (smartphone sensor data, text responses, experiment audio/video recording) will be used for analysis. We will further use extracts which CANNOT be used to identify you from the smartphone sensor and text (text responses) data in scientific publications and presentations. Anonymized data will be shared with our collaborator Dr Ana Jimenez-Tajadura (https://www.inf.uc3m.es/en/component/comprofiler/userprofile/atajadur) and her group.

ADDITIONAL USE OF DATA THAT CAN BE USED TO IDENTIFY YOU - With your permission, we will use extracts from the experiment audio/video recording in presentations or publications, for illustration purposes. We will never disclose your name or contact details with these data. Note that you could be recognised from these photo, video, or audio. In addition, the audience may record the presentation or make copies of the video/photo included in the publication and we would not have control over the use of these recordings/copies. Nevertheless, these presentations and publications can enable the research community and the general public better understand the results of our research and contribute to scientific and/or technological advancement.

Also, if you give us permission to, we would use the data we record (smartphone sensor data, text responses and experiment audio/video recording) for secondary analysis in other studies that our research team is involved in. This will support advance in better understanding of movement and the design of related technology.

ADDITIONAL USE OF DATA THAT **CANNOT** BE USED TO IDENTIFY YOU - If you give us permission, we will share anonymised data (smartphone sensor data, text responses), which CANNOT be used to identify you, with the larger EnTimeMent project partners and the wider research community, without your names or contact details included. This will further support advance in better understanding of movement and the design of related technology.

7. **What are the possible benefits of taking part?**
Whilst there are no immediate benefits for those people participating in the project, it is hoped that this work will shape future research and contribute to the development of advanced technologies for supporting engagement in physical activity for people with chronic pain and for fitness activities for the general population.

8. **What if something goes wrong?**
Extreme care will be taken in this research. However, if you wish to complain or have any concerns that are not addressed by the researcher, you should contact Prof Nadia Berthouze (nadia.berthouze@ucl.ac.uk) who is the Principal Researcher on the project. If you further feel that your complaint has not been handled to your satisfaction, you can contact the Chair of the UCL Research Ethics Committee (ethics@ucl.ac.uk).

9. **Will my taking part in this project be kept confidential?**
Your name and contact details will be kept strictly confidential. The video/audio/images that we recorded of you will also be kept strictly confidential and only used as outlined in (6) above. We would only use examples from these data in ensuing publications or presentations (e.g. academic journals, teaching presentation) if you give us the permission to do so as detailed above in (6). We would further only share DE-IDENTIFIED text and sensor data with other researchers, and only if you give us permission to.

10. Limits to confidentiality

Confidentiality will be respected unless there are compelling and legitimate reasons for this to be breached. If this happens, we will inform you of any decisions that might limit your confidentiality.

11. What will happen to the results of the research project?

The findings of our analysis of the data collected from the participants of the research project will be published in reports and articles and presented at public engagement and research talk venue. You will be able to access academic publications of these findings on the project website: https://uclic.ucl.ac.uk/people/nadia-berthouze. You will not be identifiable in these publications and presentations except you give us permission to include examples from the videos/images we collect from you. Your name and contact details will never be included in publications and presentations.

The DE-IDENTIFIED text and sensor data we collect from you, which CANNOT be used to identify you, will be made open for use by other researchers, for the benefit of scientific and technology development; but only if you give us permission to do so.

12. Local Data Protection Privacy Notice

Notice:

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our 'general' privacy notice: https://www.ucl.ac.uk/legal-services/privacy/ucl-general-research-participant-privacy-notice

The categories of personal data used will be as follows:

Name
Contact details
Body movement data
Photos and Videos and Voice in video/audio recordings
Physical activity information and information about related experiences

The lawful basis that would be used to process your *personal data* will be performance of a task in the public interest. The lawful basis used to process *special category personal data* will be for scientific and historical research or statistical purposes.

Your personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this and will endeavour to minimise the processing of personal data wherever possible. If you give us permission to make open the data to the wider research community or use it in other research projects we are involved in, processing of the personal data will continue beyond the end of the research project.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Thank you for reading this information sheet and for considering taking part in this research study.

UCL INTERACTION CENTRE
RESEARCH•CONSULTANCY•SEMINARS•COURSES

UCL Interaction Centre
2nd floor, 66 – 72 Gower St
London WC1E 6EA

CONSENT FORM FOR REMOTE PARTICIPANT

Project Title: EnTimeMent
Department: University College London Interaction Centre
Researcher: Eslam Alshami, eslam.alshami.19@ucl.ac.uk
Marusa Hrobat, marusa.hrobat.19@ucl.ac.uk
Principal Researcher: Prof Nadia Berthouze, nadia.berthouze@ucl.ac.uk

This study has been approved by the UCL Research Ethics Committee: **Project ID number 5095/001**

Thank you for considering taking part in this research. Please complete this after you have read the Information Sheet provided by the researcher.

1.	I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions which have been answered to my satisfaction.		Yes/No
2.	I confirm that I am at least 18 years old.		Yes/No
3.	I consent to participate in the study. I understand that the experiment with me will be audio/video-recorded to enable accurate record. I understand that my personal information (body movement smartphone sensor data, text question responsesvideo/audio recordings) will be used for the purposes explained to me. I understand that according to data protection legislation, 'public task' will be the lawful basis for processing for my personal data and the lawful basis used to process any special category personal data will be for scientific and historical research or statistical purposes.		Yes/No
4.	I understand that my participation is voluntary and that I am free to withdraw from the study at any time. I understand that if I decide to withdraw from the study, I can revoke my consent by signing a consent change form. I understand that I can also withdraw data I have provided, up till the 14th day after the last data I submitted, without giving a reason. If I choose to also withdraw my data, the data will no longer be used.		Yes/No
5.	I am aware of who I should contact if I wish to lodge a complaint.		Yes/No

6.	I understand that identifiable information collected will remain confidential and that all efforts will be made to ensure that I cannot be identified except where explicit consent is given below.		Yes/No
7.	I understand the risks involved during this experiment and will be responsible for my own safety.		Yes/No
Further use of my data			
8.	I agree for my sensor data, text question responses, text diary, and discussion transcripts, which CANNOT be used to identify me, to be made open to other researchers and for future research or secondary analysis, to facilitate research and innovation.		Yes/No
9.	I agree for PHOTOS recorded from me to be included in *written publications used to disseminate the project findings*. I understand that I could be recognised from such images and the audience may make copies of the image(s) and that the researcher will not have control over such copies.		Yes/No
10	I agree for PHOTOS/VIDEOS/AUDIO recorded from me to be used in *presentations used to disseminate the project findings*. I understand that I could be recognised from such photos/videos/audio and the audience may record the presentation and that the researcher will not have control over such recordings.		Yes/No
11	I agree for my personal information (smartphone sensor data, text question responses, video/audio recording) to be used for secondary analysis in other studies that the researchers of this study are involved in, *to facilitate research and innovation*.		Yes/No
12	I agree to be contacted to participate in follow up studies to this project, or in future studies of a similar nature. I understand that my name and contact details will not be shared with anyone who is not a member of this research team.		Yes/No

Preferred Contact Details (**if 'Yes' to 12**): ________________________________

FULL NAME OF PARTICIPANT: ____

Appendix O. Questionnaire of the Study 3, Experiment 3 - quantitative studies.

SOUND 1:
Now please think about the experience of the single arm raise you have just performed.
You will have to answer a few questions about it.

Please only consider the part of the arm raise that was sonified when answering the following questions.

Firstly, could you describe in your own words, how did you feel during that arm raise experience?

SOUND 1:
Please select the figure that best represents how you felt during the single arm raise experience across the two different scales.

Each scale shows different kinds of feelings: *Happy/positive* vs *unhappy/negative* and *aroused/excited* vs *unaroused/calm.*

Mood

Unhappy, Negative				**Neutral**				**Happy, Positive**

Excitement

Unaroused, Calm				**Neutral**				**Aroused, Excited**

An open ended question followed by Self-Assessment Manakins for Mood & Excitement (Bradley & Lang, 1994)

SOUND 1:
Now please select the number you think best expresses your level of agreement with the sentences below for the single arm raise

---

The sentence shown was displayed onscreen before the user answered the Likert Questions

After the sentence above was displayed, the user was asked to rate the following questions on a 7-point Likert scale. The answers in brackets correlate to the Likert Points of 1 – 4 – 7.

- As I was doing the exercise I felt:
    - (Light – Neutral – Heavy)
- As I was doing the exercise I felt:
    - (Weak – Neutral – Strong)
- As I was doing the exercise I felt:
    - (Not tired – Neutral – Tired)
- As I was doing the exercise I felt:
    - (Uncomfortable – Neutral – Uncomfortable)
- As I was doing the exercise I felt:
    - (Incapable – Neutral – Capable)
- As I was doing the exercise, I felt my movement was…:
    - (Easy – Neutral – Difficult)
- As I was doing the exercise, I felt my movement was…:
    - (Slow – Neutral – Fast)
- As I was doing the exercise, I felt my movement was…:
    - (Uncontrolled – Neutral – Controlled)
- As I was doing the exercise, I felt my movement was…:
    - (Uncoordinated – Neutral – Coordinated)
- During the audio stimulation, it seemed like the sounds I heard were produced by my own body.
    - (Strongly disagree – Neither agree or disagree – Strongly agree)
- During the audio stimulation, it seemed like the sounds I heard motivated me to do the exercise.
    - (Strongly disagree – Neither agree or disagree – strongyle agree)
- During the audio stimulation the feelings about my body were surprising and unexpected.
    - (Strongly disagree – Neither agree or disagree – strongly agree)

Appendix P. Information sheet and Consent form for the selection process of participants in the IP-study.

CARTA INFORMATIVA SOBRE EL ESTUDIO

Para la participación en este estudio, es necesario que lea atentamente la información que aparece a continuación.

Información sobre el estudio

Nos gustaría invitarle a participar en este proyecto de investigación desarrollado dentro del marco del proyecto *"ZAPATOS MÁGICOS: Mejora de los estilos de vida sedentarios mediante la alteración de la representación mental del cuerpo usando feedback sensorial"*, financiado por la Agencia Estatal de Investigación (AEI) y el Fondo Europeo de Desarrollo Regional (FEDER), dentro del Programa Estatal de I+D+i Orientado a los Retos de la Sociedad.

Solo debe participar si quiere. Elegir no tomar parte no tendrá ninguna repercusión para usted. Antes de decidir si desea participar, es importante que lea cuidadosamente la siguiente información y la discuta con otras personas si lo desea. Pregúntenos si hay algo que no está claro o si desea más información.

Con esta investigación queremos comprobar la influencia que tiene el sonido en la percepción del propio cuerpo y sus influencias en la actividad física de las personas. El objetivo final es desarrollar tecnología para ayudar a las personas a ser más activas físicamente.

Con este objetivo, nos gustaría hacerle una entrevista sobre su rutina semanal y actividad física. Le pediremos que haga varios tipos de ejercicios (ej. de fuerza o estiramiento de muslo), mientras usa un dispositivo con sensores de movimiento. Este dispositivo acompañará sus movimientos con sonido. También le pediremos que complete unos cuestionarios y que coloree unos mapas del cuerpo. Le enseñaremos como funciona el dispositivo y un diario que sirve para anotar las sensaciones durante los ejercicios, y discutiremos la posibilidad de realizar un estudio en el que usaría dicho dispositivo y diario durante una semana.

El estudio tendrá una duración máxima de una hora.

Los movimientos realizados se registrarán utilizando los sensores. La entrevista será grabada con una grabadora de audio y tomando algunas fotografías.

Los datos obtenidos a partir de las pruebas realizadas, (no aquellos datos personales), podrán ser publicados en revistas científicas así como presentados a congresos, conferencias u otros eventos relacionados con la investigación.

Con su permiso, también nos gustaría utilizar extractos de las grabaciones audio y fotografías para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajo de tesis. Tenga en cuenta que estas presentaciones pueden ser registradas por personas sin nuestro conocimiento y mostradas en las redes sociales.

<u>¿Qué implica la participación?</u>
Por un lado, esperamos que las personas que decidan participar realicen las tareas teniendo en cuenta las indicaciones dadas.

La participación en este estudio es completamente voluntaria, pudiendo retirarse una vez haya firmado el consentimiento de participación, e incluso aunque ya haya comenzado la participación en el mismo.

Recibirá una compensación económica de 10 euros por su participación.

Esta investigación no implica riesgo de ningún tipo para usted.

Todos los datos de carácter personal, obtenidos en este estudio son confidenciales y se tratarán conforme al Reglamento General de Protección de Datos.

Si decide dar el consentimiento para que podamos contar usted, tiene que firmar el documento de Consentimiento Informado.

Si tiene cualquier duda, puede preguntarles a los investigadores, y si requiere información adicional, puede ponerse en contacto con la investigadora que dirige este estudio: Ana Tajadura Jiménez, en el teléfono 91 624 9415, o escribiendo a la dirección de correo electrónico: atajadur@inf.uc3m.es

¡Gracias!

"Una manera de hacer Europa"

CONSENTIMIENTO INFORMADO Y POR ESCRITO DEL PARTICIPANTE

Yo (Nombre y Apellidos), ...

- He leído el documento informativo que acompaña a este consentimiento.
- He podido hacer preguntas.
- He recibido suficiente información. He hablado con alguno de los investigadores de este estudio.
- Comprendo que mi participación es voluntaria y soy libre de participar o no en el estudio.
- Se me ha informado que todos los datos personales obtenidos en este estudio serán confidenciales y se tratarán conforme establece el Reglamento General de protección de Datos.
- Se me ha informado de que la información obtenida sólo se utilizará para los fines específicos del estudio.
- Deseo ser informado de mis datos de carácter personal que se obtengan en el curso de la investigación.

Si No

Para los siguientes puntos, marque con un círculo "Sí" o "No" e inicialice cada punto.

____Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada por los investigadores en este proyecto en estudios de investigación adicionales SÍ / NO

____Estoy de acuerdo en que la grabación audio o fotografías sea utilizada por los investigadores para demostrar la tecnología a las personas con inactividad física y al personal clínico SÍ / NO

____Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada por los investigadores para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajos de tesis. Entiendo que estas presentaciones pueden ser registradas sin el conocimiento de los investigadores por los medios de comunicación u otros individuos / investigadores SI / NO

____ Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada en otros proyectos por miembros de este grupo de investigación SI NO

____Estoy de acuerdo en que la grabación de audio o fotografías sean compartida con investigadores que no están involucrados en este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de otros proyectos SI NO

Comprendo que puedo retirarme del estudio:

- Cuando quiera
- Sin tener que dar explicaciones
- Sin que dicha decisión tenga ninguna repercusión

Presto libremente mi conformidad para participar en el estudio y ceder mis datos de carácter personal para su tratamiento en el desarrollo y ejecución del proyecto de investigación Magicshoes. Marcar con un aspa SI ( ) NO ( )

INFORMACIÓN BÁSICA SOBRE PROTECCIÓN DE DATOS. RESPONSABLE: Universidad Carlos III de Madrid. Delegado de Protección de Datos, ver información adicional. **CONSERVACIÓN**: Se suprimirán los datos de carácter personal una vez publicados los datos de investigación. Se recogerán datos de movimiento corporal (por ejemplo, forma de andar) y de señales fisiológicas (por ejemplo, señal cardíaca) que se conservarán indefinidamente por su interés para el desarrollo de proyectos de investigación similares. Asimismo se conservarán indefinidamente los datos cuyo titular haya prestado el consentimiento informado para su uso indefinido en el tiempo. **FINALIDAD:** Investigación sobre mejora de los estilos de vida sedentarios e inactivos mediante la alteración de la representación mental del cuerpo usando feedback sensorial. **LEGITIMACIÓN:** Consentimiento del interesado **DESTINATARIOS**: Investigadores participantes en el proyecto "MagicShoes" de la Universidad Loyola Andalucía, Universidad de Sevilla, Université Pierre et Marie Curie – FRANCIA, University College London - REINO UNIDO, Tallinn University - ESTONIA. **DERECHOS:** Acceder, rectificar y suprimir los datos, así como otros derechos en los términos que se indica en la información adicional. **INFORMACIÓN ADICIONAL:** Puede consultarse la información adicional detallada sobre protección de datos en nuestra página web http://www.uc3m.es/protecciondatos

Firma del/de la participante   Firma del/de la investigador/a informador/a

Nombre y apellidos:...................   Nombre y apellidos: ....

Fecha: ...../...../.....   Fecha:...../...../.....

Appendix Q. Consent form for participants selected in the IP-study-Qualitative studies.

MagicShoes   UNIVERSIDAD LOYOLA ANDALUCÍA   Universidad Carlos III de Madrid   UNIÓN EUROPEA Fondo Europeo de Desarrollo Regional "Una manera de hacer Europa"

CONSENTIMIENTO INFORMADO Y POR ESCRITO DEL PARTICIPANTE

Yo (Nombre y Apellidos), ...

- He leído el documento informativo que acompaña a este consentimiento.
- He podido hacer preguntas.
- He recibido suficiente información. He hablado con alguno de los investigadores de este estudio.
- Comprendo que mi participación es voluntaria y soy libre de participar o no en el estudio.
- Se me ha informado que todos los datos personales obtenidos en este estudio serán confidenciales y se tratarán conforme establece el Reglamento General de protección de Datos.
- Se me ha informado de que la información obtenida sólo se utilizará para los fines específicos del estudio.
- Deseo ser informado de mis datos de carácter personal que se obtengan en el curso de la investigación.

Si No

Para los siguientes puntos, marque con un círculo "Sí" o "No" e inicialice cada punto.

____Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada por los investigadores en este proyecto en estudios de investigación adicionales SÍ / NO

____Estoy de acuerdo en que la grabación de audio o fotografías sea utilizada por los investigadores para demostrar la tecnología a las personas con inactividad física y al personal clínico SÍ / NO

____Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada por los investigadores para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajos de tesis. Entiendo que estas presentaciones pueden ser registradas sin el conocimiento de los investigadores por los medios de comunicación u otros individuos / investigadores SI / NO

____ Estoy de acuerdo en que la grabación de audio o fotografías sean utilizada en otros proyectos por miembros de este grupo de investigación SI NO

____Estoy de acuerdo en que la grabación de o audio o fotografías sean compartida con investigadores que no están involucrados en este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de este proyecto SI NO

____Estoy de acuerdo en que los investigadores en este proyecto me contacten de nuevo para futuros estudios de otros proyectos SI NO

Comprendo que puedo retirarme del estudio:

- Cuando quiera

- Sin tener que dar explicaciones
- Sin que dicha decisión tenga ninguna repercusión

Presto libremente mi conformidad para participar en el estudio y ceder mis datos de carácter personal para su tratamiento en el desarrollo y ejecución del proyecto de investigación Magicshoes. Marcar con un aspa SI ( ) NO ( )

INFORMACIÓN BÁSICA SOBRE PROTECCIÓN DE DATOS. RESPONSABLE: Universidad Carlos III de Madrid. Delegado de Protección de Datos, ver información adicional. **CONSERVACIÓN**: Se suprimirán los datos de carácter personal una vez publicados los datos de investigación. Se recogerán datos de movimiento corporal (por ejemplo, forma de andar) y de señales fisiológicas (por ejemplo, señal cardiaca) que se conservarán indefinidamente por su interés para el desarrollo de proyectos de investigación similares. Asimismo se conservarán indefinidamente los datos cuyo titular haya prestado el consentimiento informado para su uso indefinido en el tiempo. **FINALIDAD:** Investigación sobre mejora de los estilos de vida sedentarios e inactivos mediante la alteración de la representación mental del cuerpo usando feedback sensorial. **LEGITIMACIÓN:** Consentimiento del interesado **DESTINATARIOS**: Investigadores participantes en el proyecto "MagicShoes" de la Universidad Loyola Andalucía, Universidad de Sevilla, Université Pierre et Marie Curie – FRANCIA, University College London - REINO UNIDO, Tallinn University - ESTONIA. **DERECHOS:** Acceder, rectificar y suprimir los datos, así como otros derechos en los términos que se indica en la información adicional. **INFORMACIÓN ADICIONAL:** Puede consultarse la información adicional detallada sobre protección de datos en nuestra página web http://www.uc3m.es/protecciondatos

Firma del/de la participante Firma del/de la investigador/a informador/a

Nombre y apellidos:.................... Nombre y apellidos: ....

Fecha: ...../...../..... Fecha:...../...../.....

Appendix R. Information sheet and Consent form in the AP-study.

Information Sheet for Participants in Research Studies

You will be given a copy of this information sheet.

Title of Project:	**Sonification for common exercises: perception of movement qualities**
This study has been approved by the UCL Research Ethics Committee as Project ID Number:	**UC3M CEI nº 2018_004**
Name, Address and Contact Details of Investigators:	Dr Ana Tajadura Jiménez Universidad Carlos III Madrid Avda. de la Universidad, 30 28911 Leganés - Madrid Spain (+34) 91 624 94 15

We would like to invite you to participate in this research project, carried out in collaboration with Dr Ana Tajadura-Jiménez based at the Computer Science Department, Universidad Carlos III de Madrid, Spain. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, please read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or you would like more information.

The aim of this project is to develop technology to help people doing physical activity by using sound stimulation. We will ask you to fill up a questionnaire. We will ask you to do 2 common exercises -to choose among lift a leg while seating, squat without weights, step on a gym step or a clamshell exercise. The task will be repeated with 2 or 3 different sounds. Between each sound condition we will ask you to reflect on your experience while filling up a body map. We will use it to ask you some oral questions and maintain a discussion with you about your experience. At the end of all conditions, we will use all the Body Maps to discuss and compare your experiences across the sounds/exercises. Your answers can be recorded.

The study is divided into 3 sessions meant to happen in different days/weeks, each session lasting approximately 15 minutes. You can choose to participate in a raffle of 25 pounds for taking part in the study. We are exploring the influence of different sounds on your body and movement perception, and as such we are not interested in testing your performance or athletic capabilities. It is up to you to choose at your own risk what exercises to do and how many repetitions. Our suggestion is to aim for at least 3 repetitions per exercise but feel free to do less if needed.

It is up to you to decide whether or not to take part. If you choose not to participate, you won't incur any penalties or lose any benefits to which you might have been entitled. However, if you do decide to take part, you will be given this information sheet to keep and asked to sign a consent form. Even after agreeing to take part, you can still withdraw at any time and without giving a reason.

All data will be collected and stored in accordance with the Data Protection rules. Anonymous movement data from the movement sensors, and voice recordings will be stored in a computer. Researchers working with me will analyze the data collected. Anonymous data will be shared with Dr Ana Tajadura-Jiménez and her team at Universidad Carlos III de Madrid, Spain (see website http://dei.inf.uc3m.es/dei_web/dei_web/?page=people)

Informed Consent Form for Participants in Research Studies

(This form is to be completed independently by the participant after reading the Information Sheet and/or having listened to an explanation about the research.)

Title of Project: **Sonification for common exercises: perception of movement qualities**

This study has been approved by the UCL Research

Ethics Committee as Project ID Number: **UC3M CEI nº 2018_004**

Participant's Statement

I ……………………………………….., agree that I have:

- read the information sheet and/or the project has been explained to me orally;
- had the opportunity to ask questions and discuss the study; and
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that I must not take part if I am not physically able to do the tasks
- Given this I am happy to engage in mild physical activity and wear non-intrusive movement sensors
- I agree to be recorded while answering some questions

I understand that:

- anonymous movement data from the movement sensors and voice recordings will be stored in a computer.
- anonymus data will be shared with Dr Ana Tajadura-Jiménez, collaborator in this research project, based at Universidad Carlos III de Madrid, Spain.

For the following please circle **"Yes" or "No"** and initial the point.

_____ I am freely agreeing to participate in the study and consent to the processing of my personal information for the purposes of this study only and that it will not be used for any other purpose. I understand that such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection **rules**. YES / NO

_____ I am freely agreeing to the transfer of anonymous data to Dr Ana Tajadura-Jiménez, collaborator in this research project and based at Carlos III University of Madrid, Spain, for their treatment in the development and execution of this research project. YES / NO

_____ I agree to be contacted in the future by UCL researchers who would like to invite me to participate in follow-up studies YES / NO

BASIC INFORMATION ON DATA PROTECTION. RESPONSIBLE: University College London. CONSERVATION: Personal data will be deleted once the research data has been published. Body movement data and voice recordings will be collected and kept indefinitely for their interest in the development of similar research projects. Likewise, the data whose holder has given the informed consent for its use will be kept indefinitely. PURPOSE: Research on the improvement of sedentary and inactive lifestyles through the alteration of the mental representation of the body using sensory feedback LEGITIMACY: Consent of the person of interest. RECIPIENTS: Nadia Bianchi-Berthouze, University College London; Ana Tajadura-Jiménez, Universidad Carlos III de Madrid; Laia Turmo Vidal, Uppsala University. RIGHTS: Access, rectify and delete the data, as well as other rights in the terms indicated in the additional information.

Signed: Date:

Investigator's Statement

I ……………………………………………………………………..

confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date:

Appendix S. Protocol details of the (Home) IP-study

A study with 3 phases:

Phase 1: initial interview (50-60 min)
Phase 2: First week (7-9 hours & short interview)
Phase 3: Second week (7-9 hours & short interview)

Number of participants: 8 in the Phase 1 (from this select 4-6 for Phase 2)

Before the study (Inclusion criteria)

1. IPAQ - International Physical Activity Questionnaire (arrange with them a short meeting to explain and answer the questionnaire. Could be on the phone)
2. How many hours you exercise per week?
3. IFIS - International Fitness Scale (date to explain. Could be on the phone)

(This needs to be fill in before we consider inclusion in the study. Those participants scoring low in IPAQ, and exercising less than 2 hours per week will be invited to the interview)

Interview -Day 1

Materials:

1. Consent form, information sheet, participant questionnaire
2. Audio recorder
3. MagicShoes (iPod, band)
4. Diary
5. Colors box, Stickers:

Points to cover:

1. Demographics Questionnaire
2. Semi-structured Interview – get to know about you
3. Get to know the device

- Exploratory section (trying the sounds).

1. Exercise, planning
2. Tools:
   0. Diary
   1. Body maps
   2. Body feelings survey
3. A short interview per week

Before the Interview (by email)

Before to see us in our meeting I would ask you a favor, fill the calendar with the activities of your week on a daily basis.

My activities

Hours	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
07:00							
08:00							
09:00							
10:00							
11:00							
12:00							
13:00							
14:00							
15:00							
16:00							
17:00							
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
00:00							

And answer these questions

1. Do you have a smartphone?
2. If yes, do you use it to play games
    0. Do you use for physical activity management apps?
    1. If yes, Which ones?
3. Have you used movement video games (like Wii/ Kinect/Oculus or similar)?
4. Which video games did you use?
5. Did you find them useful/ engaging?
6. Could you bring your app during the interview?

Starting the interview

Thank you for agreeing to meet with me. As you know, this project is about developing healthcare technology. We are running a study to evaluate how you use this device and its sounds during physical activity sessions. This interview is of scientific interest and the information collected will be of confidential use. We don't intend to evaluate you, since we only want to understand better your opinion of the movement-sound palette and the effects of the sounds on you.
If you have any questions about the project at the end, I will be happy to answer them. I'm going to start with an interview, it will be divided in 15 min to know about you, a explorative session to learn how to use the device and get to know the different sounds you can use, 15 minutes to talk about your first impressions and 15 minutes to explain you about the home study.
Before the start, I'd like to confirm that it's okay to record our conversation or take some pictures. If you feel uncomfortable answering any of the questions, please let me know and we can go on to the next question.

Well, can we start?

Demographics -

1. Occupation:
2. Age:
3. Gender:
4. Weight:
5. Height:

1st part of the Interview – About you

1. I sent you a calendar and I want to ask you some questions

My activities

Hours	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
07:00							
08:00							
09:00							
10:00							
11:00							
12:00							
13:00							
14:00							
15:00							
16:00							
17:00							
18:00							
19:00							
20:00							
21:00							
22:00							
23:00							
00:00							

1. Are these your usual activities every week?
2. I can see you have (or have not) indicated here some moments when you exercised, did you mark all the moments when you exercised?
    0. If yes, what routine did you do to exercise?
3. Do you remember how long ago you stopped exercising?
4. Have you thought about becoming more active?
    0. What kind of exercise would you like perform?
5. Do you think you cover the exercise with the activities in your day?
    0. Could you tell me more about this activity?
6. Do you have worries/barriers about doing physical activity?
    0. If yes, what kind of worries/barriers?
    If no. Prompt: Are there any strategies that you had used to make physical activity?
1. I saw you track your activity
    0. Can you show me? (I asked them before the interview if they will be happy to bring the tracking device and show me) – easy to talk by looking at your data, you can get insights of what is interesting to them. I take a picture of the device
    1. There is a reason about why you use it.
    2. How long have you been tracking it?
    3.
    4. How do you use them? What activities are you tracking? (steps, sleep, …)

2. I saw you don't track your activity
    0. have you thought about tracking it?
3. What activities are you tracking? / What activities would you like to track? (steps, sleep, …)
4. What metrics? (HR, calories, sleep, …)
5. What kind of support do you find useful for physical activity? Additional to what is already available to you, what support would you find useful to support physical activity, e.g. a reminder, timer, tracker.

2nd part of the Interview – Learn how to use the device and tools

Exploratory section (7 minutes)

General explanation of the procedure for using sonification device

I will explain you how the device works and explain you about some tools we use to get to know about the sensations it induces in you: a questionnaire, a body map and a diary.

I will start with the use of the device, please take into account this is a prototype and that we are working on improving it.

First, (raspberry, band and iPod) you will use a band to track your movements and get sound in response, for example leg lifting or stretching. You are going to use an iPod to calibrate and select the sound that you wish. When you perform your movements, the device gives auditory feedback.

Let's turn on the device, band, and iPod (I show the switch for the first two). Open the browser and safari and automatically you will see the application web.

At the beginning of every exercise session you need to calibrate (no sound). You will need to set a minimum and maximum position; Let's do an example:

Can I put the band in your left leg? … When your foot is on the ground would be minimum position, so you can press the button "set minimum position" now raise and keep your leg this is your maximum, then press "set maximum position". Press the button "ok".

Now here there is a list of movements with various sounds, you can select the sounds for thigh stretch, wind/water/mechanical/beep or leg lift water/beep/tone/tone Up/tone Down. Choose the sound you want to try and press the "play button" the app is asking you "which leg" press the button "left". Now, replicate my movement (I show how to move his/her leg).

After 3-5 repetitions. Well, when you finish your exercise you press "stop button" and the app will ask you "Continue to survey?" press "ok". Fill in your name and you will see a survey about how you felt during your exercise in relation with your body. Press over this line (I will do it for the participant to see), do the same for the other fields. Press the button "Validate" and "back to exercise".

Remember its ok that you feel I just want to know the effects and understand how the people feel with this sounds. Now you know how to work the device, let's continue.

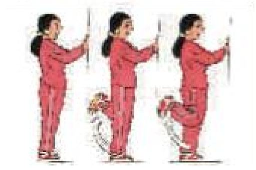
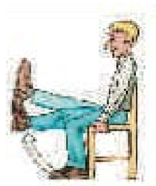
I show the Diary (I will put an introduction sheet in the diary and manual to use the device)

Choosing the Exercise

What kind of exercise would you like to do using your arm or legs?

Maybe there is a part of your body that you feel is more difficult to exercise?

Prompt. I have some examples of movements proposed (NHS -thinking about be more active?) that you have in the diary.

Exercise		
General warm up	Heel lifts 	Bend and stretch 
The strengthening & toning program	Lateral raises (if you have dumbbells you can do it with/without them) 	Leg lift 
	Knee lifts 	Legs – seated to standing (You can do it with/without a chair) 
The flexibility program	Thigh stretch 	Side arm raise 

Diary

[Once the exercise finishes and they have, filled in the survey.]
I'm going to give you a diary to record your thoughts and experiences of using the device while doing exercise. Calibration, sound, movement, feeling in your body etc. Please, think about sounds that would be more engaging and useful for you. Use the iPod to take the photo of the place to help me better understand the context.
See the other pages in the document Diary appendix:

Exercise recommended: _________________________
or to explored (describe with some words): _________________________
Date: ___________________ (dd/mm/aaaa)
Time: ___________________ (hh:mm)

I performed the exercise in: _____________________
with the sound/s: ____
During the exercise I felt: ____
I think the sound/s alter or change my body feelings is/are _________________
______________ because____
____
The ________ sound make me feel different in my body with this movement
due to: ____
____
Also, I think: ____
____
____

Which emojis identify you?

Take a picture/selfie of you exercising in the place

Body map

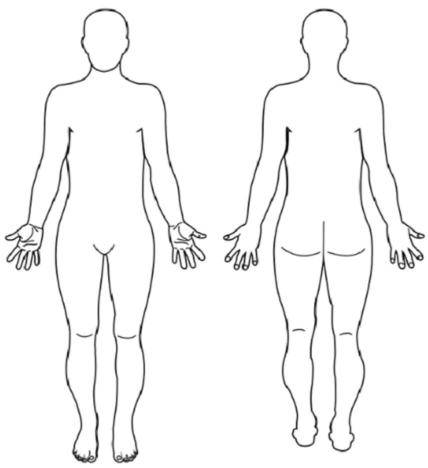
I need you see this body map and think about your feelings while you were doing the exercise. You will underline the word that describes a feeling you had and color that part of your body that made you feel in this way.

SOUND:

As I was doing the excercise. I/it felt

STRONG / WEAK
TENSE / RELAXED
FLEXIBLE / STIFF
FLUID / NOT FLUID
AGILE / AGILE
CONTROL / NOT IN CONTROL
SLOW / QUICK
HEAVY / LIGHT
PLEASING / UN PLEASING

____
____
____



Rest…… do you have any question about what we have been discussing?

3rd part of the Interview – About the Home Study

In brief. If you decide to take part in the home study, I would need you do this at least with 2-3 exercises everyday. You will repeat this process for each exercise: 1) Use the device, 2) answer the survey, 3) write in the diary, and 4) color the body map (integrated in the diary).

Time of exercising

The exercise will take you approximately 20-30 minutes that is the recommend by the booklet (NHS -thinking about be more active?). We need you to move your body like this for at least 30 minutes over the course of a day - this can include adding together shorter bouts of activity in blocks of 10 – 15 minutes throughout the day to total 30 minutes a day. We would like you to do it every day of the next week.

Set and repetitions

You can start doing 15 repetitions easily, take 1 minute's rest (if you want change of sound) and repeat a 2nd set of 8-15 repetitions. If you feel good. Once you can do 2 sets of 15 repetitions easily, adding a 3rd set of 8-15 repetitions will make your muscles work a little harder.

Do you expect to do? (30 minutes)

	Time (10-15 minutes)	Strength (set & reps)	Flexibility
1 week			

According with the calendar I would like to know approximately when you are planning to perform the exercise. The idea is that if you agree, I could send you some reminder at this time. Of course, my details are on the information sheet and you can contact me at any time during the running of the study to ask any questions.

So with this information, would you be happy to take part in the home study? Could you confirm your availability to do it in the next two weeks?

Perfect! So, since you have indicated your interest in taking part in the home study, once I analyze all the interviews, I will call you to let you know if we have the possibility to take you as a participant.

I will provide you then with an information sheet and consent form, and you will have the opportunity to ask me any questions/ concerns.

If you are still happy to participate, I will give you the device and a diary and the 1-week study will start then.

We have finished do you have any question? thanks for coming and I will contact you to notify you If you are selected.

Post-Interview: after Phase 2 and Phase 3

Review the diary to make some questions

1. Let's see what you expected to do and see what you did (I show the activity calendars)
   0. What do you think about that?
   1. Is it what you expected?
2. Let's see the diary, could you tell me about your general thoughts during this week?
3. What did you think of the sounds?
4. What sounds made your exercise easier?
5. Which sound/s did you like for this exercise?
6. Which one helped you more with your movement?
7. Do you think the sounds alter or change your body feelings?

   Prompt. See your body maps think about your body, how do you feel it, how do you feel your leg, heavy or light, quicker of movement, if your movement were in control.

Which sound/s make you feel different in your body?

1. Do you think the sounds give you some body awareness?
2. What sound would motivate them to do this activity?
3. Which one helped you with the sense of having a body more/less flexible?
4. Which one helped you with the sense of having a body more/less strong?
5. Which one helped you with the sense of having a body more/less agile?

6. Which one helped you with the sense of having a heart or breath more/less accelerated?
7. Did you felt other body feeling?
8. How did sounds affect your movement (if at all)
9. Did it help?
10. Engaging?
11. Distracting?
12. Confusing?
13. Encouraging?
14. What would you add to promote long-term engagement?
15. Did the sound make you more/ less aware of the control of your movement?
16. Of course, we are limited but what kind of exercise do you want to do using your arm and leg?
17. Talking about the device in a first experience, what did you like or dislike about the device?
18. How did you use the device?
19. Did it help? In what way?
20. Talking about the device in a first week, what did you like or dislike about the device?
21. In what situations would you use the device?
    0. Why? Could you give me an example?
22. What would you add to the device to be used during exercise?
23. Change?
24. Remove?
25. Do you still feel motivated to use the device?
26. If he/she have tracker, can I see your device?

Another consent form after week 1 – do you want to continue one more week?

Appendix T. Summary of the interview for the AP-study and IP-study

- **Demo of SoniBand**

Here is an example of the metaphorical sonifications and the SoniBand interface.

https://youtu.be/Ibzw-tCFl0k

- **Semi-structured interview questions**

The questions below are from the semi-structured interviews in both studies. The last set of 2.1.3 questions were specifically tailored to the inactive population

- **Interview prompts**

How was the movement? How did you feel?

How does the sound fit the movement? What do you think of the sound in this exercise?

Did it feel like the sound you heard was produced by you? If so, how? If not, why not?

This sound, what does it make you think about when doing the exercise?

What are you paying attention to now? / Where is your attention?

Does the sound help in any way or the opposite?

Does the sound change how you perceive the exercise?

Did you feel tired doing the exercise? Why, why not? / Was it difficult to perform the exercise? Why/why not?

What is your overall impression and feeling of doing the exercise (which this sound)? How did it feel? Why? Why not?

  - **Specific questions for the Body Maps**

Does the sound reflect any of the properties here? Where in the body, anywhere in particular?

What do you mean/understand by <property>?

In what ways you felt <property>?

Do you think that the sound <x> had any effect on how you perceived <property>?

If so, how?

If not: What did have an effect on you feeling <property>?

Did the sound <x> effect what you felt in any other way?

Was your movement <property> or you felt your body <property>?

Why do you think you felt <property> during the exercise?

Do you think that the sound <x> affected how you felt during the exercise?

If so, how? What properties?

  - **Comparison at the end of the session**

<open all the body maps and put them side by side if they have illustrated them> <depending on what they had -differences, similitudes- tailor the questions>

How would you compare the different exercises with the different sounds?

Which one (movement and sound) do you prefer the most and which one the least? Why?

Which property was more interesting or meaningful for you? And why?

Which sound was more interesting or meaningful for you? And why?

Which exercise was more interesting or meaningful for you? And why?

- **Reflection at the end of the week (inactive people)**

Let's look at the diary. Could you tell me your general thoughts this week?

What did you think of the sound <> while as the week progressed?

What sounds facilitated your exercise? Why?

What sound / s did you like for this exercise? Why?

Tell me, how <sound> helped you the most with your movement?

Do you think <sounds> alter or change the feelings in your body?

What <sound> would you use to represent each of these qualities?

What <sound> would you choose for each exercise and why?

Appendix U. Diary used in the (home) IP-study

Actividad Física | Diario

Este estudio está siendo realizado por investigadores de:
UC3M y Universidad de Loyola Andalucía,
Ha sido aprobado por el Delegado de Ética de la UC3M
www.magicshoes.es - jley@inf.uc3m.es

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Nombre del participante: ……………………………………………………………………….....

Numero de participante: ………………………………………………………………………

Correo electrónico: ………………………………………………………………

Fecha de inicio (dd/mm/aaaa): …………………………………………………….

3

Hola,

¡Gracias una vez más por aceptar participar en nuestro estudio!

Hemos preparado este diario para ayudarle a participar en el estudio. Comenzamos con información general y lo que se espera de usted. Hemos incluido una hoja de información, algunos materiales de ejemplo, recomendaciones sobre dónde usar el dispositivo y algunos consejos rápidos. Sugerimos que lea esta sección al comienzo del estudio.

Después de esto, hemos incluido una copia del cronograma de estudio, incluidas las fechas aproximadas y lo que haremos en las reuniones. No se preocupe; le recordaremos lo que se espera antes de cada reunión.

También hay un formulario en el que puede completar la hora y el lugar de nuestras reuniones, para que no lo olvide. Nos pondremos en contacto por correo electrónico para organizar cada una de las reuniones más cerca del momento.

La mayor parte del diario se compone de ejercicios por página. Use esto para registrar se interacción con el dispositivo en cuanto a movimiento y sonidos. Hay más detalles y una ejemplo al comienzo del diario.

Recolectaremos el diario al final del estudio, ¡por favor cuídelo!

Si tiene alguna pregunta o problema jley@inf.uc3m.es o si necesita contactar con la persona responsable del proyecto (Ana Tajadura Jiménez) puede hacerlo escribiendo a atajadur@inf.uc3m.es

Gracias, *Judith y el equipo de magic-shoes*

4

Información sobre el estudio

Nos gustaría invitarle a participar en este proyecto de investigación desarrollado dentro del marco del proyecto "ZAPATOS MÁGICOS: Mejora de los estilos de vida sedentarios mediante la alteración de la representación mental del cuerpo usando feedback sensorial", financiado por la Agencia Estatal de Investigación (AEI) y el Fondo Europeo de Desarrollo Regional (FEDER), dentro del Programa Estatal de I+D+i Orientado a los Retos de la Sociedad.

Solo debe participar si quiere. Elegir no tomar parte no tendrá ninguna repercusión para usted. Antes de decidir si desea participar, es importante que lea cuidadosamente la siguiente información y la discuta con otras personas si lo desea. Pregúntenos si hay algo que no está claro o si desea más información.

Con esta investigación queremos comprobar la influencia que tiene el sonido en la percepción del propio cuerpo y sus influencias en la actividad física de las personas. El objetivo final es desarrollar tecnología para ayudar a las personas a ser más activas físicamente.

Con este objetivo, le pediremos que haga varios tipos de ejercicios (ej. de fuerza o estiramiento de muslo), mientras usa sensores de movimiento. También podrá escuchar sonidos, al hacer estas actividades. Las actividades se registrarán utilizando los sensores. También le pediremos que complete cuestionario sobre sus percepciones corporales, escriba en un diario pensamientos y sensaciones del cuerpo, y coloree en un mapa del cuerpo sus sensaciones durante el estudio. Si alguna vez olvida usar el dispositivo, toma nota de esto y avísenos al final de la semana.

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El estudio durará 1 semana en total, el uso mínimo del dispositivo y el diario en conjunto sería de una hora cada día.

Con su permiso, es posible que queramos utilizar la información que nos ha proporcionado (no sus datos personales) para la enseñanza, conferencias, presentaciones, publicaciones y / o trabajos de tesis, pero siempre de forma anónima.

Esta investigación no implica ningún riesgo para usted.

Todos los datos personales obtenidos en este estudio son confidenciales y serán tratados de acuerdo con el Reglamento General de Protección de Datos.

Puede contactarnos en cualquier momento enviando un correo electrónico a jley@inf.uc3m.es o si necesita contactar con la persona responsable del proyecto (Ana Tajadura Jiménez) puede hacerlo escribiendo a atajadur@inf.uc3m.es

¡Gracias!

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Instrucciones de estudio

Las siguientes páginas ofrecen más información sobre el estudio que está realizando. Le recomendamos que lea detenidamente esta información al comienzo del estudio.

Seguridad

Como se menciona en la hoja de información, cambiar los regímenes de ejercicio puede causar problemas de salud. Consulte a su médico de cabecera antes de realizar cambios en su nivel de actividad física.

El uso de un dispositivo móvil, como el sensor o un iPod, puede distraer y causar accidentes. Solo interactúe con los dispositivos cuando sea seguro y sensato hacerlo.

La raspberry, R-ioT y iPod

La "raspberry" es una pequeña computadora conectada a un sensor R-ioT (dentro de la banda), un monitor de actividad, que cuando se conecta a la extremidad registrará los movimientos que ha realizado durante todo el día (consulte la siguiente sección para obtener una descripción general de los lugares del cuerpo apropiados para usar el dispositivo).

La "raspberry" incluye conectividad Wi-Fi para conectarse a su iPod (que le proporcionamos). La batería del R-ioT debe durar al menos la duración del estudio, pero si encuentra que se está agotando puede cargarla con la batería portátil (la batería se puede cargar como normalmente carga el teléfono o el iPod).

Donde usar la banda

La banda utiliza un sensor que puede detectar sus movimientos cuando se coloca en el tobillo, muslo, bíceps o antebrazo.

El dispositivo NO es resistente al agua, así que recuerde quitarlo de su ropa antes de lavarla y no lo use mientras nada, en la bañera o la ducha.

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Diario

En este libro, le proporcionamos un diario y mapas corporales. Le recomendamos que tome notas sobre sus interacciones con el dispositivo. Durante los días del estudio, le enviaremos recordatorios diarios según el calendario acordado.

Le proporcionamos un ejemplo de diario para que entienda como usarlo. Sin embargo, no se sienta restringido por este ejemplo, utilice el diario en cualquier momento o como lo considere útil. Hay **pegatinas** que representan visualmente cómo se sintió durante el ejercicio escuchando los sonidos.

Además, le proporcionamos una figura general de un **mapa corporal** para reflejar cómo el sonido le hace sentir durante los movimientos. Seleccionará de una lista de palabras o escribirá las propias y coloreará la parte de su cuerpo donde tiene estos sentimientos. Finalmente, le pedimos algunas **fotos** del lugar o tal vez un "selfie" donde se le vea en el momento del ejercicio, esto es para saber más sobre el contexto del ejercicio y las sensaciones que ha descrito en el cuestionario y el diario.

Recolectaremos su diario al final del estudio, así que recuerde traerlo. Además, no olvide que todos los datos recopilados se mantendrán en la más estricta confidencialidad.

Si tiene algún problema o duda: jley@inf.uc3m.es

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Programa

Entrevistas

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Programa del estudio

Las siguientes páginas ofrecen un calendario para todo el estudio. Tenga en cuenta que debido a la gran cantidad de participantes, todas las fechas son aproximadas. Cada reunión se organizará individualmente con usted, por correo electrónico. Si en algún momento no está disponible, infórmenos.

- Puede ser útil completar la fecha, la hora y el lugar de las entrevistas.
- Además, informe cualquier cambio en su actividad física o métodos de transporte.
- Informe cualquier día en que olvidó usar el dispositivo

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Entrevista inicial y reunión	
Parte 1 • Planificar un calendario semanal • Recibir y completar el formulario de consentimiento, la hoja de información y el folleto. • Devolver el formulario de consentimiento firmado **Parte 2** Recibir raspi, R-ioT, iPod, batería portátil y diario	
Día:	
Hora:	
Lugar:	

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Entrevista	
• Discutir cualquier cambio en el comportamiento, dificultades o desafíos durante la semana pasada. • Hablar sobre las respuestas al diario y los mapas corporales.	
Día:	
Hora:	
Lugar:	

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Entrevista	
• Discutir cualquier cambio en el comportamiento, dificultades o desafíos durante la semana pasada. • Hablar sobre las respuestas al diario y los mapas corporales.	
Día:	
Hora:	
Lugar:	

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Instrucciones

Cómo encender los dispositivos y calibrar el movimiento.

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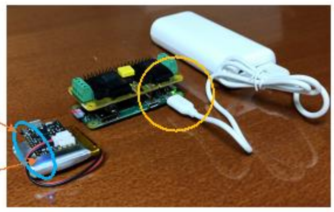
Dispositivo (sensores):
Conecte el raspi (sensor verde y grande) con la batería portátil como en la imagen de la derecho (espere 1 minuto para comenzar).
Banda, encienda el R-ioT el pequeño sensor dentro de la bolsa, verá la 1ra luz roja, la 2da verde y la 3ra azul, es decir, está conectado con el raspi.



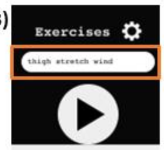
iPod:
1. Presione el botón superior (para encender/apagar)
2. Abre el navegador safari.
3. Cargará automáticamente la página Magic-shoes (192.168.1.1)

Página principal

1) Presione el botón de calibración desde la página principal.
2) **Siempre** calibre con ***Left***: Cuando tu brazo o pierna este en la posición inicial presione "set minimum position" y cuando este en la posición final "set maximum position", por último "ok" para terminar de calibrar.

1)


3) Presione sobre **thigh stretch wind** para ver la lista de posible sonidos.
Ir ala página 15

3)


Posición del sensor:
Interruptor en dirección al suelo

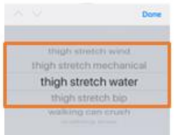
Ejemplo de calibración

1. Posición inicial 2. Posición Final

3.


2)


Lista de sonidos en thigh stretch:
Wind, Mechanical, Water, Bip



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5) Seleccione el sonido, presione Done y el boto "play" para iniciar.
6) Cuando pregunte que pierna/brazo usar seleccione la izquierda - "which leg?" presione "left". VER NOTA
7) Comience su rutina. Cuanto termine la primer serie (15 repeticiones) detenga el sonido "stop" e inicie el cuestionario - "Continue to survey?" presione "ok".
8) Escriba su nombre, luego mueva el punto al lado que expresa cómo se siente/sintió en el ejercicio.
9) Presione "validate" para guardar el cuestionario.
10) Presione "back to exercise"
11) <u>**Apague**</u> los sensores, y el iPod cuando termine tu rutina.

5)


Nota: No se preocupe si usa el pie/brazo derecho o izquierdo.

6)


7) 8) 9)


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Ejercicios

Puede seleccionar los ejercicios de la lista o proponer los suyos.

Serie y repeticiones

Realice 2-3 series por cada programa:

1) Seleccione un movimiento de cada programa o proponga uno, recomiendo iniciar con calentamiento.
2) Realice 15 repeticiones (1 serie),
3) Responda el cuestionario (*survey*) mientras descansa 1 minuto (si lo desea cambie aquí de sonido) y
4) Repita un segundo conjunto de 8-15 repeticiones y responda el cuestionario

Programa	Ejercicios	
Calentamiento general	Levantamiento de talones 	Doblar y estirar 
El programa de fortalecimiento y tonificación	Elevaciones laterales (si tienes pesas puedes hacerlo con / sin ellas) 	Levantamiento de pierna 
	Levantamiento de rodilla 	Sentadillas (puede hacerlo con/sin silla) 
El programa de flexibilidad	Estiramiento de muslo 	Elevación del brazo lateral 

4) Si se siente bien durante el calentamiento y ve que puede hacer 2 series de 15 repeticiones fácilmente, agregue una 3ra serie de 8-15 repeticiones
5) Responde el diario y mapa corporal
6) Luego repitiendo los pasos del programa 1-5, continúe con el programa de fuerza y finalmente con el programa de flexibilidad.

Diario

Por movimientos y sonidos, realizará al menos tres ejercicios de la lista propuesta.

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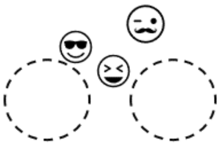
Ejemplo

Ejercicio recomendado: Levantamiento de pierna
O para explorar (describir con algunas palabras): ____________
Use el sensor en la pierna (o muslo/brazo/bíceps) derecha/izquierda o ambas
Día: 22/11/2019 (dd/mm/aaaa)
Hora: 20:00 (hh:mm)

Usa el iPod para tomar la foto

¿Qué "emojis" expresan cómo se sintió durante el ejercicio?



Realicé el ejercicio en: mi cuarto, usando una silla, y en mi piso
con el sonido / s: Water y bip
puede usar el mismo sonido o cambiar durante el descanso (entre las series).
Durante el ejercicio sentí: Aquí puede poner cómo se siente su cuerpo
trate de pensar en la parte que mueve, o si se aceleran su respiración y corazón
Mis pensamientos durante el ejercicio fueron Si estuvo enfocado en el ejercicio
o el sonido, o talvez en un recuerdo.
porque por qué relaciona este sonido con estos pensamientos
____
El sonido me hace sentir diferente en mi cuerpo con este movimiento:
Cualquier emoción está bien, no dudes en escribirlas
____
____
Además, me gustaría decir: ____________
Comentario adicionales
____

Pega aquí las pegatinas relacionadas con su estado de ánimo durante el ejercicio.

Tome una foto / "selfie" haciendo ejercicio en el lugar

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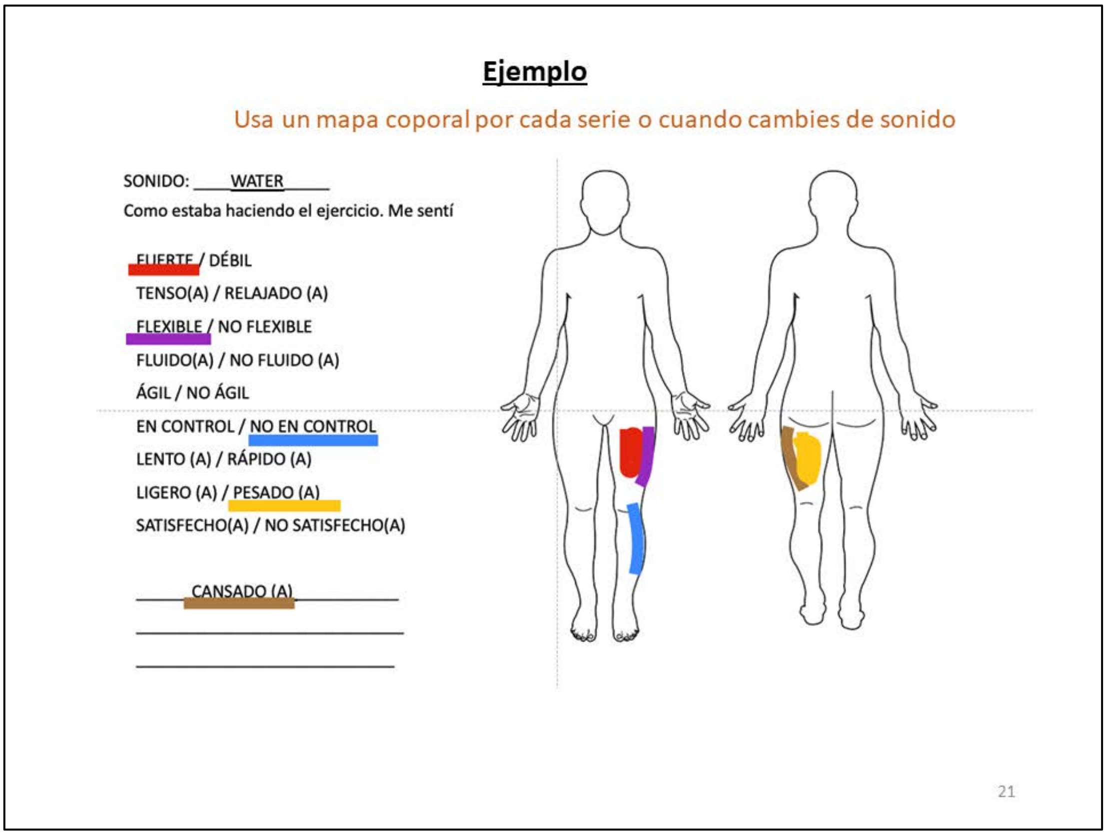
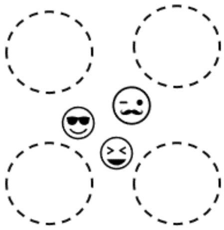


Different options were provided to help supplement the diary. See below, in the diary were 3 journal sheets per day and 3 body maps for each journal sheet (9 total per day).

Ejercicio recomendado: ________________________
O para explorar (describir con algunas palabras): _____________________
Use el sensor en __________________
Día: __________________ (dd/mm/aaaa)
Hora: ___________________ (hh:mm)

Realicé el ejercicio en: ____________________________________
Con el sonido/s: ____
Durante el ejercicio sentí: __como el viento______________________________________
____
Creo que el/los sonido/s que altera o cambia los sentimientos de mi cuerpo es son _________________________________. _______________
porque____
____
El sonido ______________ me hace sentir diferente en mi cuerpo con este movimiento debido a: ____
____
Además, creo que: ____
____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?



Tome una foto / “selfie” haciendo ejercicio en el lugar

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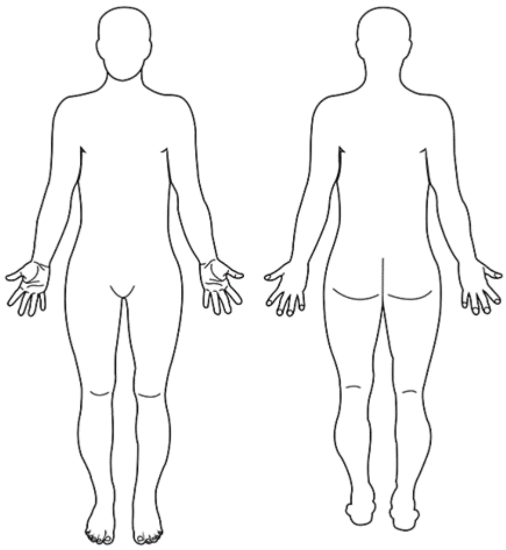
SONIDO: ____________________
Como estaba haciendo el ejercicio. Me sentí

FUERTE / DÉBIL
TENSO(A) / RELAJADO (A)
FLEXIBLE / NO FLEXIBLE
FLUIDO(A) / NO FLUIDO (A)
ÁGIL / NO ÁGIL
EN CONTROL / NO EN CONTROL
LENTO (A) / RÁPIDO (A)
LIGERO (A) / PESADO (A)
SATISFECHO(A) / NO SATISFECHO(A)

____
____
____



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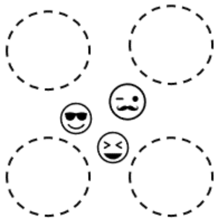
Ejercicio recomendado: ____________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en ____________________
Día: ____________________ (dd/mm/aaaa)
Hora: ____________________ (hh:mm)

Realicé el ejercicio en: ____________________
Con el sonido/s: ____________________
Durante el ejercicio sentí: ____________________
____
Mis pensamientos durante el ejercicio fueron ____________________
porque____________________
____
El sonido ______________me hace sentir diferente en mi cuerpo con este movimiento: ____________________
____
____
Además, me gustaría decir: ____________________
____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?



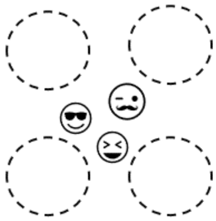
Tome una foto / "selfie" haciendo ejercicio en el lugar

26

Ejercicio recomendado: ____________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en ____________________
Día: ____________________ (dd/mm/aaaa)
Hora: ____________________ (hh:mm)

Realicé el ejercicio en: ____________________
Con el sonido/s: ____________________
Durante el ejercicio sentí: ____________________
____
Creo que el/los sonido/s que me ayudaron más son ____________________
porque____________________
____
El/los sonido/s que no me ayudaron son ____________________
porque____________________
El sonido que me gustó para este ejercicio ____________________ la razón es
____
____
Además, me gustaría decir: ____________________
____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?



Tome una foto / "selfie" haciendo ejercicio en el lugar

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Ejercicio recomendado: ____________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en ____________________
Día: ____________________ (dd/mm/aaaa)
Hora: ____________________ (hh:mm)

Realicé el ejercicio en: ____________________
Con el sonido/s: ____________________

El sonido ____________ me motiva a ____________________
Creo que el sonido ____________ me hace hacer ejercicio más fácil ____________
debido a ____________________
No entiendo el sonido ____________ porque ____________________
____
Me sentí mas consiente de mi cuerpo con el sonido ____________________
____
Me sentí flexible con ____________ también sentí mi cuerpo ____________
____
Notas (mi opinión): ____________________
____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?

Tome una foto / "selfie" haciendo ejercicio en el lugar

34

Ejercicio recomendado: ____________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en ____________________

Día: ____________________ (dd/mm/aaaa)
Hora: ____________________ (hh:mm)

Realicé el ejercicio en: ____________________
Con el sonido/s: ____________________
El sonido ____________ me ayuda a: ____________________

Creo que mis movimientos fueron ____________________
porque ____________________
No me gusta el sonido ____________, debido a ____________________
____
Sentí que el sonido me distraía: ____________________
____
Me sentí atraído/a o "enchangado/a" con el sonido de ____________________
____
Me gustaría agregar: ____________________
____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?

Tome una foto / "selfie" haciendo ejercicio en el lugar

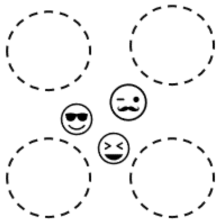
38

Ejercicio recomendado: ______________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en _________________

Día: _________________ (dd/mm/aaaa)
Hora: __________________ (hh:mm)

Realicé el ejercicio en: __________________________________
Con el sonido/s: ____
Me sentí fuerte/débil con el sonido _______ porque __________________
____
Mis movimientos durante el ejercicio fueron _________________________
porque ____
____
Mi sensación corporal cuando estaba haciendo ejercicio fue: ___________
____
Sentí que el sonido me animó: _________________________________
____
Me sentí confuso con el sonido de ___________ también sentí: ________
____
También quiero agregar: ____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?



Tome una foto / "selfie" haciendo ejercicio en el lugar

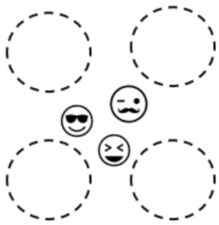
42

Ejercicio recomendado: ______________________
O para explorar (describir con algunas palabras): ____________________
Use el sensor en _________________

Día: _________________ (dd/mm/aaaa)
Hora: __________________ (hh:mm)

Realicé el ejercicio en: __________________________________
Con el sonido/s: ____
Mis movimientos tenían menos / más control porque: __________________
____
Me sentí (más / menos) ágil con el sonido ________, porque ___________
____.
Sentí mi cuerpo (más / menos) cansado con: ____________________ podría ser porque: ____.
Sentí que el sonido ________ me motivaba porque: ____________________
____.
Tuve otros sentimientos corporales con el sonido de _____________ porque _____________________ mis sentimientos fueron__________________
____
____
Notas: ____
____
____

¿Qué emojis expresan cómo te sentiste durante el ejercicio?



Tome una foto / "selfie" haciendo ejercicio en el lugar

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Appendix V. Barriers Questionnaire for PA (BQPA)

A continuación, se presenta una lista de posibles obstáculos con los que te puedes encontrar a la hora de realizar actividad física. (Rick et al., 2020)

Indica desde 0 (totalmente en desacuerdo) a 4 (totalmente de acuerdo) en qué medida estas barreras te suponen o han supuesto una dificultad en algún momento para realizar actividad física. Ten en cuenta que en las frases que leerás a continuación, las palabras "actividad física", "ejercicio" y "deporte" se utilizan indistintamente, significando lo mismo.

En la casilla en blanco a la derecha: Escriba un **0** si está **En total desacuerdo** con la afirmación. Escriba un **1** si está **Bastante en desacuerdo**. Escriba un **2** si su respuesta es **Ni de acuerdo ni en desacuerdo**. Escriba un **3** si está **Bastante de acuerdo**. Escriba un **4** si está **Totalmente de acuerdo**.	
Me da miedo hacerme daño al hacer algún ejercicio	
Me da vergüenza que me vean haciendo deporte	
Necesito la recomendación de un médico o profesional para hacer ejercicio	
No me siento a gusto conmigo mismo/a	
Hacer deporte es para gente diferente a mí (por ej. más joven, de otra cultura, de otro sexo)	
Creo que hacer ejercicio es innecesario	
No tengo dónde hacer el deporte que me gusta	
No me siento apoyado/a emocionalmente por mis familiares y/o amigos para hacer ejercicio	
Necesito que alguien se ocupe de mis tareas mientras yo hago deporte	
Me hace falta alguien que me guíe o ayude a hacer actividad física porque tengo limitaciones físicas que no me permiten hacerlo solo/a	
El deporte que me gusta es demasiado caro	
No me gustan las sensaciones de mi cuerpo cuando hago ejercicio (por ej. sentir como se mueve, como se acelera mi corazón, mi respiración)	
Los técnicos o instructores no me dan el apoyo que necesito	
Me falta equipamiento para realizar la actividad física que me motiva	
No encuentro lugares que me gusten o me inspiren para hacer actividad física	
Los demás me miran mal o se ríen de mi cuando hago ejercicio	
No me gusta hacer deporte	
No soy capaz de generar tiempo para mí y hacer deporte	
Me da pereza hacer ejercicio	

Tengo que cuidar a mis hijas/os u otra/s persona/s a mi cargo	
No me siento capaz de hacer ejercicio	
No estoy en forma como para hacer deporte	
El dolor que siento cuando hago ejercicio me dificulta o me impide hacerlo	
No hay buenas opciones de transporte en mi zona	
No tengo acompañante para ir a hacer ejercicio	
Me preocupa no saber si mis movimientos son correctos cuando hago ejercicio	
No me planteo hacer deporte porque tengo que ocuparme de las tareas del hogar	
Mi estado de salud me impide hacer actividad física	
No tengo costumbre de hacer ejercicio	
En mi entorno no se promueve el hacer deporte	
Generalmente, me siento cansada/o para hacer ejercicio	
Mi cuerpo no mejora cuando hago ejercicio y eso me desmotiva	
No encuentro ayudas económicas que me permitan hacer ejercicio	
No se me da bien hacer ejercicio	
El mal tiempo (caluroso, lluvioso, frío, etc.) que suele hacer donde vivo me dificulta hacer deporte	
El estrés que tengo me impide practicar deporte	
Priorizo otras cosas antes que el ejercicio	
Cuando estoy de mal humor no me apetece hacer ejercicio	
Es peligroso hacer deporte en el lugar o zona donde vivo	
Hacer deporte supone un reto demasiado grande para mí	
Me desmotiva que no se cumplan mis objetivos a nivel deportivo	
Hacer deporte no es uno de mis propósitos en la vida	
No obtengo ningún premio cuando hago ejercicio (por ej. dinero, comer un dulce)	
No practico deporte porque se estropea mi aspecto (por ej. el pelo, maquillaje)	
No me gusta sentirme obligado/a a hacer ejercicio	
Me siento demasiado deprimido/a para hacer deporte	
Tengo problemas de ansiedad que me dificultan hacer ejercicio	
Dudo que mi salud dependa de hacer actividad física	
Se me olvida hacer ejercicio	
Me cuesta hacer deporte porque nunca recuerdo los ejercicios que he aprendido	
Me parece algo egoísta dedicarme a hacer deporte y no a otras cosas	

Hacer ejercicio me genera ansiedad	
No soy una persona deportista	
No tengo confianza en mí mismo/a a la hora de realizar actividad física	
Me falta información sobre la actividad física (por ej. sus beneficios, cómo y dónde practicarlos, etc.)	
He sufrido algún suceso traumático en mi vida que me ha llevado a no practicar ejercicio (por ej. muerte de un familiar, pérdida del trabajo).	
He tenido experiencias negativas con el deporte	
Nunca he hecho ejercicio de forma regular	
No encuentro clases de actividad física en mi idioma	
Mis estudios o trabajo me impiden hacer actividad física	
No soy capaz de seguir haciendo deporte cuando me surge alguna dificultad física (por ej. cuando siento dolor, un ejercicio no me sale, tengo agujetas)	