Designing a gesture-sound wearable system to motivate physical activity by altering body perception

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ABSTRACT

People, through their bodily actions, engage in sensorimotor loops that connect them to the world and to their own bodies. People's brains integrate the incoming sensory information to form mental representations of their body appearance and capabilities. Technology provides exceptional opportunities to tweak sensorimotor loops and provide people with different experiences of their bodies. We recently showed that real-time sound feedback on one's movement (sonic avatar) can be

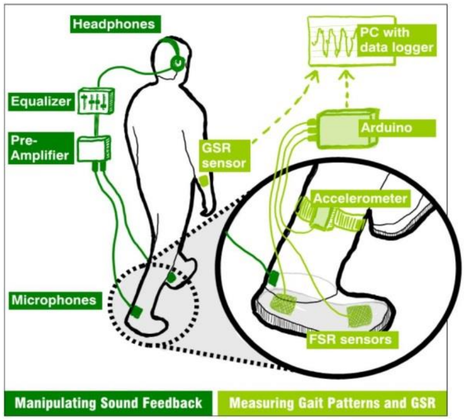

Figure 1: One of the first MAGICSHOES prototypes developed by our team in 2014-2015. It was used to alter in real-time the actual footstep sounds resulting from walking and to measure the effects in gait patterns (measured with accelerometer and force sensitive resistors - FSR) and in arousal (measured by a galvanic skin response sensor - GSR). Short adaptation periods to altered walking sounds led to thinner body estimation, to adoption of gait patterns typical of lighter bodies and to an enhanced emotional state [23].

used for sensory alteration of people's body perception, and in turn provoke enhanced motor behaviour, confidence and motivation for physical activity (PA) in people while increasing their positive emotions towards their own bodies. Here we describe the design process of a wearable prototype that aims to investigate how we can overcome known body-perception-related psychological barriers to PA by employing action-sound loops. The prototype consists of sensors that capture people's bodily actions and a gesture-sound palette that allows different action-sound mappings. Grounded in neuroscientific, clinical and sports psychology studies on body perception and PA, the ultimate design aim is to enhance PA in inactive populations by provoking changes on their bodily experience.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Gestural input** • **Applied computing → Sound and music computing; Law, social and behavioral sciences;** *Psychology*;

KEYWORDS

Interactive systems design; sound; body movement; physical activity; psychological factors; self-care technology design; self-tracking; self-perception; body-perception; embodied cognition; health

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1 INTRODUCTION

Enhancing people's adherence to physical activity (PA) through technology remains an important human-computer interaction (HCI) challenge. In the last decade, the HCI research community has attempted to address the challenge of physical inactivity by leveraging sensing devices for activity tracking and providing motivating feedback, mostly building on cognitive behavioural theories [6]. However, a recent review of the field [8] has highlighted key limitations of the approach used and called for reconsidering this work through the lens of critical but unaddressed factors that may be responsible for undermining adherence to PA. In our work, we are responding to this call. We argue that existing technologies and related research endeavours in HCI do not address crucial psychological factors in adherence to PA, including factors linked to people's body perception. Here, we present our novel approach through the framework of the MAGICSHOES project (www.magicshoes.es). We propose a rethink of PA technologies by embedding body-related factors in the design process [27], and exploit recent neuroscientific findings that body-perceptions can be changed via specially designed sensory feedback [2,14,19,28]. In the next sections, we provide the background that motivates/informs our work. We then present an overview of the wearable technology we are designing based on user needs, which captures and sonifies body movement with the aim of altering people's bodily experience.

Table 1: Design principles (DP) based on body-related psychological factors that need to be altered according to identified user needs

	Description	*Dimensions acted upon*
DP1	Enhance perceived body appearance	Perceived weight, size or shape
DP2	Increase perceived muscular strength	Perceived power
DP3	Increase perceived body speed/agility	Perceived body fluidity and flexibility
DP4	Enhance proprioception (sense of body parts position; effort employed in movement)	Confidence in one's body, sense of control, self-efficacy, self-esteem
DP5	Provide sense of body progression or achievement	Self-efficacy, self-esteem
DP6	Encourage or invite movement ("body pulling")	Intrinsic motivation
DP7	Take attention away from one's body	Anxiety
DP8	Allow system tailoring according to the user needs or preferences. Tailoring done by the user alone or with help of professional.	Overarching DP that applies to all DPs

2 BACKGROUND

Identifying user needs: Physical inactivity and body-self relations

In a recent study based on an extensive literature review and a survey study we identified significant correlations between PA participation and self-esteem, motivation and body-self relations, such as concerns about one's body appearance, and perceptions of one's muscular strength and speed/agility [17]. While current technology often uses strategies to make PA more enjoyable or finding time for PA (e.g. by making a schedule/routine or adapting the activity), strategies related to thoughts about one's body are rarely addressed. The possibility of altering perceived physical appearance, physical capabilities and the overall self-concept of one's own body through sensory feedback may offer a practical way to make people feel good about their bodies [3,15]; this may facilitate healthy changes in self-esteem and confidence in one's body. The identified user needs [17], and the potential strategies to address them, are at the root of our technology design process and are summarized as Design Principles in Table 1. To cater for different users' needs, an overarching design principle is to allow tailoring the system and sensory feedback according to user needs and preferences.

Using sound in response to body actions to alter mental body-representations

Theories of 'forward internal models' of sensorimotor loops [30] suggest that we predict the sensory feedback from our actions (e.g., seeing our hand moving) by taking into account, among other factors, mental models of one's body (body-representations). When feedback and predictions do not match, body-representations may be updated. Neuroscientific research has indeed shown that sensory feedback can be used to alter people's mental body-representations [2,14,19,27,28]. For example, observing a very long arm in VR can result in the illusion of owning that arm, if the arm moves in synchrony with one's actual arm [9]. This opens opportunities for technology to tweak sensorimotor loops and provide people with different bodily experiences. Using gesture-sound interactive systems we showed for the first time that sound-feedback on one's actions can alter body-representations [28]. For such updates to happen sound-feedback needs to be felt as generated by one's body and the spatiotemporal sound alterations need to be kept below certain limits [26]. We then investigated the possibility of altering body-representations with sound, to enhance physical performance and positive attention to one's body, while creating confidence and motivation for PA, both in healthy people and in people with low back pain [13,21-24]. For instance, real-time alteration of gait and positive emotional state were driven by change in sound, which in turn altered people's perceptions of their body size/weight (see Fig. 1).

Gesture-sound technologies for PA

This possibility of altering body-representations while enhancing people's feelings towards their own body, the quality of and motivation for PA through the use of specially designed auditory feedback opens new avenues for motivating PA in the general population and for therapies/self-management of the many clinical conditions accompanied by body-representation distortions using wearable technologies. Sound-driven alterations in body-representation are more easily applied in ubiquitous settings than visual-driven ones, as sound does not interfere with movement, allows presenting several streams in parallel and continuously [7]. Overall, sound offers an excellent potential for consumer applications used during walking, when headphones and portable sound devices are often used. Sound

Figure 2: Overview of the wearable prototype, which includes force-sensitive resistors (FSRs) in the shoe insoles and a 9-axis movement sensor (IMU) worn on the lower leg. Note that the device can be easily modified to fit/sonify another part of the body (e.g. upper leg, arm, trunk).

has been shown to have positive effects in sport, dance and motor rehabilitation [4,5,16,18,20,29], such as enhancing body awareness and movement coordination. Sound feedback on body movement can for example, ease motor learning by enhancing body-related information, such as the distance to a target posture [11,20], and improve self-efficacy [21,22]. In the next section, we present an overview of the wearable prototype we are developing that integrates a sound-gesture palette for tailoring the sound feedback according to user needs. The ultimate aim for this technology is to use sound to alter people's perception of their body appearance and capabilities as they walk or do other physical activity, resulting in more active motion patterns and positive emotional states. Our prototype should allow an investigation of the following three research questions:

- Can gesture-sound systems be used to promote PA in inactive people by altering body perception?
- What design principles should (and could) be integrated in the gesture-sound wearable system to make it effective to motivate PA? (see Table 1 as starting point, to be refined through research).
- How should the principles be translated into gesture-sound mappings?

3 SYSTEM OVERVIEW

The prototype consists of sensors that capture people's bodily actions (wearable device) as inputs to a gesture-sound palette that allows different gesture-sound mappings. Note that this differs from the prototype in Fig. 1 in which the actual footstep sounds were modified. The prototype also allows the measurement of the user behaviour changes. The version of the wearable device we present here (see Fig. 2), integrates in the front and rear part of shoe insoles force-sensitive resistors (FSR; 1.75x1.5" sensing area) that detect the exerted force by feet against the ground (as in the prototype in Figure 1). FSRs are connected to a Bitalino R-IoT sensor module that embeds a 9-axis IMU sensor with 3 accelerometers, 3 gyroscopes and 3 magnetometers, all 16 bit. In Fig. 2 the sensor module is placed on the lower leg, but note that it could be worn on any other body part (e.g. upper arm). The data are sent wirelessly (WiFi) using the OSC protocol to a computer running Max/MSP. Overall, our software allows for gesture-to-audio synthesis in which motor behaviour, as quantified by FSRs and 9-axes signals, triggers or sculpts the sound feedback. Guided by the design principles in Table 1, we defined various sonification paradigms as a starting point (see Table 2). We then implemented a gesture-sound palette allowing to test/refine the paradigms in future user studies, as explained below. The sounds are produced using different sound synthesis engines and mapping strategies.

First, we implemented a series of sound engines using descriptor-based concatenative synthesis [1]. This allows for playing small pieces of recorded sounds with a quasi-continuous control on their technique, implemented in Max (Cycling'74) with the library MuBu for Max (freely available):

- Mappings 1-2: the FSRs in the shoes are mapped to either "water splash" sounds or to "aluminium can crash" sounds with various pitches, intensities, etc (related to paradigms 1, 2, 5, 7 in Table 2).
- Mappings 3-4: the leg angles (computed using both accelerometer and gyroscope data) are either mapped to "underwater" sounds or "mechanical" sounds (related to paradigms 3-5, 7).

Second, we implemented another type of sound engine, by using a physical model as an intermediate layer in the sensor-to-sound mapping process [12]. Example mapping 5 uses such a technique:

Table 2: Sonification paradigms informed by Design Principles

Description of paradigm	*Related Design Principles*
1. Sonification of impact events (i.e. footstep) to alter perceived body size/weight (e.g. high pitch sounds correspond to smaller bodies) [23,24]	DP1
2. Sonification of impact events (i.e. footstep) to alter perceived applied strength (e.g. "weak" vs "strong" sounds) [25]	DP2
3. Sonification of body movement (e.g. moving leg) with fluid vs rigid sounds to alter perceived body flexibility/fluidity	DP3
4. Sonification of movement angles to provide position information and enhance sense of control, confidence, self-efficacy [21,24]	DP4
5. Sonification changes/evolves with time to give impressions of body progression or achievement (e.g. body changes from rigid/mechanical to fluid) [22]	DP5
6. Sonification of movement initiation events (e.g. triggering a sound that "pulls the body") to encourage continuation [13]	DP6
7. Use of attention grabbing events/Pleasant events to take attention away from one's body [22]	DP7

- Mapping 5: FSR lift drives a ballistic motion that controls the pitch variation of a recorded sound. This favours the perception of "throwing an object in the air" or "body pulling" (paradigm 6).

Third, we used a series of patches for adding simple musical concepts or synthetic sounds. Example mappings 6-7 use such a technique:

- Mappings 6-7: Leg angles are mapped to musical scales and FM sounds (paradigms 4, 5, 7).

Note that some of these mappings may not sound natural to users the first times. As discussed in [26-28], the mappings need to enhance the sense of agency so that the sound is perceived as directly produced by one's body action and potentially lead to body perception changes. Our next step is conducting user studies to clarify what mappings work best in terms of being perceived as directly created by one's body and what gesture-sound mappings are better associated by users to certain bodily sensations (e.g. feeling lighter, stronger, bigger, more flexible, etc). These initial explorations will be followed by in-depth controlled studies investigating the influence of selected mappings in body perception and its relation to PA in order to address the research questions. The proposed lists of design principles and sonification paradigms will be iteratively refined throughout these studies.

4 CONCLUSION

Clinical and sports psychology studies have shown psychological factors in the inactive population that may be critical to PA, which include factors linked to people's perceptions of their body. We propose a novel design approach to technology for PA that addresses some of these factors. Building on neuroscientific studies showing that body perceptions can be altered through specially designed sound feedback on bodily actions, we set a series of design principles with the ultimate design aim of enhancing PA in inactive population by provoking changes on their bodily experience. Based on these principles, we developed a prototype of a movement-tracking wearable device and a gesture-sound palette, which will allow investigating what design principles should be integrated in the gesture-sound wearable system (and how) to effectively provoke changes in people's bodily experiences (e.g. feeling stronger or lighter) and in turn enhance people's involvement in PA. Future work includes conducting such research in controlled studies and, eventually, in-the-wild studies, as well as looking at combination of sound with other sensory feedback (for related work see the Magic Lining project [10]). We hope that our novel approach invites other people to rethink design solutions for technology to improve uptake of PA by addressing psychological needs, including those linked to body perception.

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