Using Sound and Movement Signals for Foot Augmentation and Body Transformation Experiences

Ana Tajadura-Jiménez
Universidad Carlos III de Madrid
Madrid, Spain
UCL Interaction Centre
London, United Kingdom
atajadur@inf.uc3m.es

Abstract

Body perception is not fixed but continuously updated through sensory and motor signals. Building on neuroscientific, HCI and AI research, our lab investigates Body Transformation Experiences — perceptual illusions in which altered sensory bodily feedback induces feelings of one's body changing. In this paper we introduce two paradigms and prototypes which use sound and movement signals and are designed for foot augmentation, along with experimental results from various application contexts. By presenting these paradigms and experimental findings, this paper aligns with the workshop themes of "modalities and methods for foot augmentation" and "design challenges and guidelines", contributing insights into how multisensory feedback can reshape body perception and movement behavior.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**; **Auditory feedback**; • **Applied computing → Psychology**.

Keywords

Foot Augmentation; Body Transformation Experiences; Multisensory Body Perception; Multimodal Interfaces; Movement Sonification; Interaction Styles; Emotion; Embodied Interaction, Wearables

ACM Reference Format:

Ana Tajadura-Jiménez. 2025. Using Sound and Movement Signals for Foot Augmentation and Body Transformation Experiences. In . ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 Introduction

Neuroscientific and HCI research has shown that body perceptions are not fixed but are continuously updated through sensory and motor signals [1, 12]. At our lab (www.imbodylab.com), we build on this work to explore **Body Transformation Experiences**—perceptual illusions where altered sensory bodily feedback makes individuals feel as if their body has changed. Examples include experiencing longer arms [24], a smaller or larger body [16, 18], or enhanced physical capabilities [8, 9]. These experiences can impact motor behavior [19, 22], social behavior [13], emotions [8, 19], body satisfaction [16], and self-identity [3]. Such findings open up exciting applications in sports, health [7], avatar embodiment [15], entertainment, and the Arts.

Our research focuses on how sound and other sensory signals, together with movement signals, can induce these body perception illusions. In this position paper, we introduce two paradigms and prototypes designed for foot augmentation, along with experimental results from various application contexts. This work aligns with the workshop themes of "modalities and methods for foot augmentation" and "design challenges and guidelines."

2 Augmenting Footstep Sounds: Magic Shoes and SoniWeight Shoes

The sounds our feet produce while walking carry rich information about our bodies. For example, when hearing an unknown walker, we can often infer various characteristics—such as posture [14], gender, emotional state, and even shoe size [6]—without needing to see that walker. Research has shown that heavier bodies produce lower-frequency sounds compared to lighter bodies [11], and although we may not be consciously aware of it, we naturally pick up on these auditory cues to form judgments about other people's bodies.

But what about our own walking sounds? Could they also shape our perception of our own bodies? We designed a **foot augmentation system** that modifies in real-time footstep sounds produced as people walk to create a **Human Augmentation experience**. The system consists of strap sandals equipped with microphones to capture footstep sounds, which are then processed using either an analog equalizer (see Fig. 1A) [19] or a DSP electronic board (Bela.io; see Fig. 1B) [5] to filter the sound. The processed sounds mimic those produced by either a lighter or heavier body, depending on the settings. By altering the frequency spectra of footstep sounds, the system induces the illusion of having a heavier or lighter body—a phenomenon known as the **"Footsteps Illusion"** (see Figure 1C) [19, 23]. These shifts in body perception are accompanied by measurable changes in emotion and gait, as recorded by sensors and self-reports.

We have been exploring the potential of this system across various application domains. Our research shows that altering footstep sounds during **exertion-based activities**, such as using a gym step or climbing stairs, can make exercise feel easier or more difficult [23]. For individuals with **Complex Regional Pain Syndrome** (CRPS), we have investigated how this system can help restore the

Conference'17, Washington, DC, USA

ACM ISBN 978-x-xxxx-xxxx-x/YYYY/MM
https://doi.org/10.1145/nnnnnnn.nnnnnnn

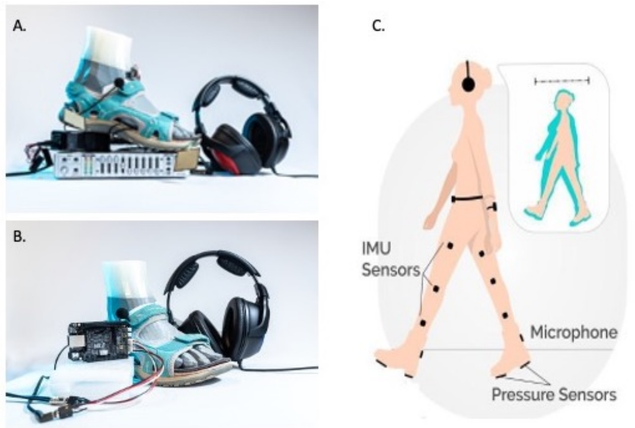

Figure 1: As light as the sound of your footsteps. The system, in its analog version (A – called 'Magic Shoes') [19] and digital version (B – called 'SoniWeight Shoes") [4, 5], is designed for walking while listening to high/low frequency versions of one's footstep sounds. (C) The "Footsteeps Illusion" - Short adaptation periods lead to estimates of one's body as being thinner/lighter or wider/heavier and to changes in gait and emotion as measured by pressure sensors (force-sensitive resistors - FSRs) and Inertial Motion Unit (IMU) sensors [19].

perception of "missing" body parts in their mental body representation [20]. Additionally, augmenting footstep sounds for people with **chronic stroke** has been found to modify gait parameters related to left-right asymmetry, supporting gait rehabilitation [7]. We have also used this system to study multisensory integration of external body signals in individuals with **eating disorders** [21]. More recently, a study with over 100 participants explored individual differences in the system's effects, paving the way for **personalized applications** [4]. Furthermore, we have investigated enhancing the experience with scents [2] and how the system can influence perceptions of femininity and masculinity [3, 4, 23]. Finally, we are now examining the system's potential to alter emotional states through body perception changes in individuals with **depressive symptoms**.

3 Metaphorical Sonification of Foot Movement: SoniShoes and SoniBand

Beyond our focus on naturally produced sounds, such as footstep sounds, we are also exploring **movement sonification for foot augmentation**. Figure 2 illustrates **Sonishoes** [9], a system incorporating a BITalino R-IoT with an IMU and two FSR sensors (see Figure 2B). Movement data is wirelessly transmitted to a Raspberry Pi Zero, which can be controlled via a web browser on a smartphone. A modified version of this system, **Soniband** [10], excludes the FSR sensors and is embedded in a silicone bracelet, allowing it to be worn on different body parts (e.g., arm, leg, waist; see Figure 2A). Our system enables interactive movement sonification, where body movement and foot pressure are transformed into virtually any sound. We have employed naturalistic-environmental sounds, such as water, wind, or mechanical gear sounds, with the aim to link sounds (e.g. water) to body perceptions (e.g. being fluid and moving faster). Beyond the metaphorical associations triggered by the nature of the sound, we also examine how the movement-related information embedded in the sound influences perception. For example, "Water" sonification plays a continuous flowing water sound throughout the movement, with an added "splash" sound near the calibrated end position; "Mechanical" sonification mimics the sound of rusty gears, playing continuously and gradually shifting frequency as it approaches the calibrated end position [10].

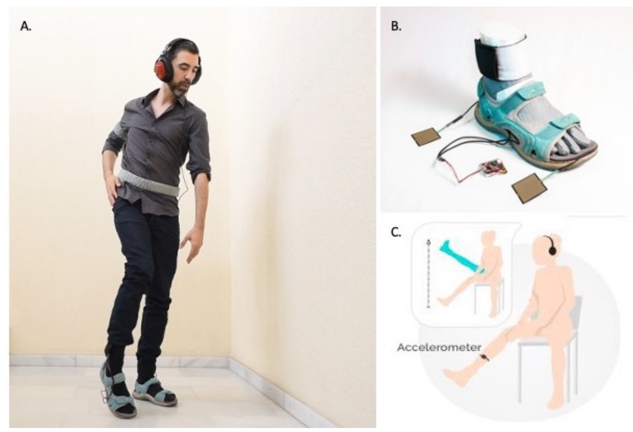

Figure 2: Pushed by sound. (A) A person wearing SoniShoes [9] and Soniband [10]. (B) Sonishoes: a system based on shoes for the sonification of foot movement. It incorporates a BITalino R-IoT with an IMU and two FSR sensors. (C) Rising a body part triggers a simultaneous rising pitch sound, which leads to changes in proprioceptive awareness of the sonified body part and an increase in perceived body capability [8].

We have been investigating the effects of these sounds on body perception and movement. Our studies have shown that using this system can lead to changes in **perceived body capabilities** (e.g., feeling stronger, more flexible, or agile), as well as movement quality (e.g., acceleration) and physical exertion levels (e.g., the number of repetitions in strengthening or flexibility exercises) [9, 10]. Additionally, the system has been used to sonify movement with non-naturalistic sounds, where pitch changes evoke spatial movement. We found that movement sonification using such spatial metaphors can influence proprioception of the sonified body part (Figure 2C), enhance sensations of body lightness, and increase motivation to move, thereby supporting exercise [8, 17]. This research has led to a set of design considerations aimed at modifying body and movement perception and supporting physical activity in physically inactive individuals.

4 Acknowledgments

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 101002711) and the Agencia Estatal de Investigación MICIU/AEI/10.13039/501100011033 (grant PID2023-150259OB-C21, Cofunded by the European Union).

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