Body Transformation: An Experiential Quality of Sensory Feedback Wearables for Altering Body Perception

Laia Turmo Vidal
Universidad Carlos III de Madrid
Madrid, Spain
laia.turmo@uc3m.es

Ana Tajadura-Jiménez
Universidad Carlos III de Madrid
Madrid, Spain
atajadur@inf.uc3m.es

José Manuel Vega-Cebrián
Universidad Carlos III de Madrid
Madrid, Spain
josemanuel.vega@uc3m.es

Judith Ley-Flores
Universidad Carlos III de Madrid
Madrid, Spain
jley@inf.uc3m.es

Joaquín Roberto Díaz Durán
Universidad Carlos III de Madrid
Madrid, Spain
jodiazd@pa.uc3m.es

Elena Márquez Segura
Universidad Carlos III de Madrid
Madrid, Spain
emarquez@pa.uc3m.es

ABSTRACT

Body perception has a significant impact on people's motor, emotional, and social functioning. We evaluated the potential of four different existing wearable prototypes, which provide sound or haptic bodily feedback to alter body perception. In a Research through Design workshop, we invited professional dancers as expert study participants to explore and assess our prototypes. Based on the workshop's insights, we articulate the experiential quality of *Body Transformation*, which characterizes how dancers perceive and experience their bodies while interacting with such prototypes. The quality encompasses a perceptual and holistic transformation, impacting the feelings about body, movement and emotions, and where the sensory feedback's evocative power is crucial. Additionally, it elicits different transformation valuations. We contribute a deeper understanding of the impact of sensory feedback on body perception, its potential for transforming people's overall body experience, and methodological insights on the potential of working with dancers to evaluate wearable sensory technology.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**; **Interaction design theory, concepts and paradigms**.

KEYWORDS

Body Transformation, Sensory Feedback, Dancers, Sonification, Haptic Feedback, Experiential Quality

ACM Reference Format:

Laia Turmo Vidal, Ana Tajadura-Jiménez, José Manuel Vega-Cebrián, Judith Ley-Flores, Joaquín Roberto Díaz Durán, and Elena Márquez Segura. 2024. *Body Transformation*: An Experiential Quality of Sensory Feedback Wearables for Altering Body Perception. In *Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '24), February 11–14, 2024, Cork, Ireland*. ACM, New York, NY, USA, 19 pages. https://doi.org/10.1145/3623509.3633373

1 INTRODUCTION

The term body perception is used to refer to a multifaceted phenomenon that encompasses both perceptual (e.g. perceived body size) and attitudinal (e.g. emotional feelings and thoughts towards body size) components [22]. Body perceptions, as well as appraisals that people have and make on their own body size, shape, appearance or capabilities, have a significant impact on motor, emotional, and social functioning, and are intricate with many health conditions [2, 37, 79, 91]. Importantly, cognitive neuroscientific research has widely shown that body perception is highly plastic [11, 25, 65, 93, 117], and can be altered through multisensory signals related to the body. This has fostered strands of research both within cognitive neuroscience and HCI exploring the potential of sensory technologies providing bodily feedback to affect the own body perception [6, 49, 55, 59, 77, 108, 109, 123].

Prior works showing the capacity of sensory inputs to alter body perception have focused mostly on visual stimuli [59, 78, 129], which can be very constraining of body movement, or have been confined to laboratory or highly controlled environments in quantitative studies, and focusing on the effects of sensory feedback on singular components of body perception (e.g. [6, 17, 49, 59–61, 87, 104, 109, 114, 129]). Hence, to date, there is a lack of understanding of the holistic impact that sensory feedback technologies that affect body perception can have on people's experience of their own body in complex and ubiquitous contexts beyond the lab. Similarly, there is a lack of knowledge on how to evaluate such holistic experience, and how to foster similar experiences through design.

To address this gap, in this paper we present **Body Transformation** as an experiential quality [46, 66–68], a conceptual knowledge form characterizing the experience of people interacting with certain kinds of, or "genres," of technologies [66–68]. In our work, such category are technologies for altering body perception, represented by four wearables deployed in a case study. As an experiential quality, our concept emerges analytically, reflecting patterns related to the lived experiences of people interacting with them: in basis to how our participants experienced their own body when interacting

TEI '24, February 11–14, 2024, Cork, Ireland

ACM ISBN 979-8-4007-0402-4/24/02…$15.00
https://doi.org/10.1145/3623509.3633373

with four sensory feedback wearables that alter their body perception. We articulate the experiential quality based on the results of a case study: we engaged in a Research through Design [38] workshop, in which we qualitatively evaluated the potential of four different existing sound and haptic feedback wearable prototypes to alter professional dancers' perceptions of their own body. We invited dancers as somatic connoisseurs [88], with a unique relationship to their own body perception and movement, characterized by proprioceptive acuity [48], heightened action-perception links and movement control [9], as well as the capacity to articulate nuanced and elusive aspects of their somatic experience. We believed that inviting dancers as expert study participants could support nuanced assessments of wearable sensory technology prototypes.

During the workshop, 9 dancers experienced first hand different existing prototypes: two sonification prototypes with proven capacity to alter body perception in other populations (SoniBand [62] and SoniShoes [61]); and two novel prototypes, one sonification wearable initially developed for art-based research and performance (Joakinator [26]); and a vibrotactile prototype (Vibrants) resulting from early design explorations [107], yet never evaluated with real participants. We engaged in a qualitative analysis of interviews and several auto-documentation forms such as sheets that included questions and body maps [3, 124]. From our results, we surface the impact of each prototype on body, movement and emotional feelings. We characterize Body Transformation as an experiential quality that fosters a *perceptual* and *holistic* transformation of body perception. This transformation is often underpinned by the sensory feedback's *evocative power*, and it fosters different and varied *transformation valuations*. We ground each characteristic of the experiential quality on our empirics and our cognitive neuroscience theoretical foundation.

Our work presents contributions at an empirical, a conceptual, and a methodological level. Empirically, we contribute with novel insights on the effects of SoniShoes and SoniBand on a new, body expert, population (dancers). We also introduce two new prototypes, Joakinator and Vibrants, with the potential to alter body perception. Conceptually, based on the findings of our workshop we contribute the experiential quality of *Body Transformation*, which characterizes in a holistic way the experience of interacting with the perception-altering prototypes in our workshop. This quality can be used *analytically*, to better understand and evaluate the impact of sensory feedback technologies designed to alter body perception. As an experiential quality, Body Transformation holds potential to be used evaluative, to develop design judgment ability of similar technologies [66]. We also propose open and preliminary related design inspirations towards employing the quality*generatively* in future works, by using the characterization of the concept and the proposed design inspirations to craft a "preferred state" [134] towards which to aim in the design process.

These two contributions add to, and extend, prior work on sensory technologies to alter body perception (e.g. [7, 19, 32, 51, 55, 60, 62, 73, 77, 86, 99, 103, 105, 107–110, 113–118, 129]). Finally, methodologically, our work shows the potential of working with dancers as expert study participants to elicit nuanced assessments of wearable technology prototypes. This aligns with and extends prior works [31, 64] proposing inviting dancers as a relevant expert population into the design process, and more broadly, to prior work on dancers and dance within HCI (e.g. [32, 52, 64, 74, 81, 130, 133]) and TEI in particular (e.g. [14, 40, 45, 47, 50, 56, 71, 75, 85, 92, 100].

2 BACKGROUND

We provide a theoretical grounding on cognitive neuroscience of body perception that will help us to organize and articulate our results and contributions. We also review related works on sensory feedback and dancers within HCI.

2.1 Theoretical Foundations in Cognitive Neuroscience

The way people perceive their own body (e.g. its appearance, configuration, and motor abilities) influences how they move and interact with the environment and with others [37, 95]. Body perceptions is a complex and multifaceted phenomena, that encompasses perceptions of one's body configuration, such as position of body parts and kinematics (i.e. **motor capabilities**), often referred to as *body schema* [59, 70], used for tasks such as walking and tool manipulation; and perceptions of **body appearance**, including shape and size, often known as *body image* [25, 65]. Body image encompasses both *perceptual* (accuracy in perceiving one's own body size and shape) and *attitudinal* (emotional feelings towards one's body image) facets [22, 112]. Indeed, how people perceive their body (e.g. big, light, strong) and their movement (e.g. fast, fluid) is interrelated with emotions [60]. While these various facets of the experience are tightly intertwined and co-shaping each other [95], the extent to which they intertwine with each other is not well established [22, 41], has been largely overlooked in prior work [39], or studied separately. In this work, we study body experience holistically, looking at the technology impact on both perceptual and attitudinal components, as well as the (perceived) impact on various related dimensions, such as behaviour and emotion. To do so, we will draw from these theoretical underpinnings that have been used in prior work (e.g. [60]), and use them as analytical lenses to articulate the felt, subjective effects of sensory illusions on body perception. These lenses include self-reported *feelings about the body* itself (i.e. subjective perceptions associated to body image, body capabilities and body awareness); *feelings about the movement* (subjective perceptions associated to the movement of the body, such as movement qualities, or difficulty in moving); and *emotional feelings* (emotions felt when experiencing the illusion). We will employ these overarching analytical lenses to report on our results in Section 5.

2.2 Altering Body Perception Through Sensory Feedback

A person's physical body may not change quickly, but their body perception is highly plastic [11, 25, 65, 93, 117]. Numerous neuroscience studies have demonstrated that through multisensory signals it is possible to create perceptual illusions of one's body changing, such as having a shorter/taller or slimmer/wider body [78, 108, 129]. These illusions can be designed, but the principles behind their creation and impact are still being studied [65, 90].

Bodily illusions may arise from perceived sensory "conflicts" between different bodily signals [54, 131], e.g.: seeing a rubber hand being touched while receiving synchronous touch to one's own hand results in people reporting feeling as if the rubber hand were theirs, revealing a three-way interaction between vision, touch, and proprioception [11]. Using VR and involving visual, proprioceptive and/or haptic feedback may elicit similar bodily illusions, e.g.: embodying a body different from one's own, even if this body has a different shape [55], weight [77], or size [108, 129] than ours. The sensory feedback generated by such systems is associated with their bodies through two interrelated mechanisms [111]: a *spatiotemporal multisensory mechanism* based on the spatiotemporal correlation of multisensory signals; and *individual and sociocultural* influences, involving memories and prior experiences that shape perception and sociocultural norms that affect the body perception in specific ways (e.g. body ideals) [111].

2.2.1 *Sound and Haptic Feedback.*

Most technologies for altering body perception are confined to laboratory or highly controlled environments, as they restrict whole-body movements and primarily depend on visual stimuli [94, 101]. Here, we focus on sound and touch feedback because they are less distracting and constraining as individuals do not need to visually fixate on the feedback [15, 44]. Further, they can be embedded into wearable technology that can be used in complex and dynamic contexts of use [128]. Next, we present relevant prior work using sound and haptic feedback that we will use in section 6 to discuss the novelty and contributions of our work.

Sound feedback. Wearable technologies utilizing sound to provide feedback on movement have been used in sports, dance, motor learning, health and rehabilitation [17, 18, 42, 72, 84, 87, 89]. Works have looked at the possibilities of interactive movement sonification (where body movements are transformed into real-time auditory feedback) to enhance movement execution and control (for reviews see [7, 86, 118]), movement awareness towards an improved performance [51, 73, 105]), or in clinical settings [99]. The impact of sound on altering body perception has been the subject of recent research [103]. Manipulations of hand tapping sounds may induce illusions of having a longer arm, which affect reaching movements [113, 115, 117], or also alter the perceived strength applied to tapping [110]. Creaky sounds can make individuals feel stiffer [103], and sounds produced by a robotic arm can induce "robotized" feelings [58], if paired with pressure applied to the body or with body movement. Similarly, altering the frequency of footstep sounds produced as people walk can influence perceived body weight and impact gait, emotional state, and feelings of being quicker and more feminine [19, 109, 114]. These studies highlight the need to consider the interaction of sociocultural factors such as gender stereotypes and weight stigma rooted in societal body ideals [119] with the effects of sensory feedback to alter perceptions (e.g. [107, 108, 114, 116]. Other sonification research has shown its positive effects on body and emotional feelings [61], and that sounds with metaphors evoke additional meanings that exert sociocultural effects on their perception [82, 111], e.g.: a mechanical sound is associated with machinery and chains, evoking heaviness. Finally, soma design works exploring sound have also shown the potential of sound stimuli and feedback to influence body awareness, e.g. [20, 21, 32].

Haptic feedback. Recent years have seen a proliferation of haptic feedback wearables for well-being (e.g. to improve body posture [4, 132]), sports and physical activity (e.g.: to provide information on movement trajectory for movement guidance [5, 36, 102]), posture and body alignment (e.g. [125]) or motor task learning (e.g.[96], see overviews in [27, 97]). Neuroscience research has shown that haptic cues can be used to affect people's perception of their own body, mostly in combination with visual feedback [11, 122] and with a major focus on the perceptual components of the experience. In HCI, works within soma design have also explored the use of haptics to alter body perception, e.g.: the Soma Mat uses thermal stimuli to guide attention and raise awareness of different body areas [49, 69, 106]; the Soma Corset affects the wearer's perception of their own body, leading to uncanny experiences and twisted perceptions [53]; the Breathing Wings offers different tactile feedback to help re-experiencing particular body parts [123].

Some soma design works are also relevant for our paper because they argue for the transformative potential of design [106]: the potential of assembling the sociodigital materials to create experiences and foster engagements that transform the participants' experience, creating alternative, richer and potentially better ways of being in the world. We will refer back to this transformative potential when articulating the experiential quality *Body Transformation.*

2.3 Prior Work on Dancers

Researching and designing technologies for dancers and dance contexts has a rich tradition in TEI, and more broadly in HCI (see [50, 133] for recent reviews). Yet, to the best of our knowledge no prior work has focused on altering their body perception. Most prior works have focused on supporting creative processes and outcomes of dancing [133], developing technology to e.g. disrupt or prompt movements [52], explore interactions with instruments [74], or adding visualizations [8, 13]. Within TEI in particular, several works have focused on supporting interactive dance performances and installations (e.g. [14, 45, 47, 56, 92]). Some works have focused on the motor learning aspects of dance, e.g. understanding the underlying learning processes and strategies [80] and developing technology to support them [23, 81, 85, 120, 130]. Some works have centered on the communication aspect, mapping out communicative challenges [121] and supporting a dialogue [43, 71] between stakeholders. Other works have centered on the analysis of dance [133]. Finally, a more limited body of work has investigated dancers and dance methodologically, for example, reflecting on the tensions in integrating technology in dance [31], as inspiration for designers to design interactions [40, 75]. More relevant for our work, some prior work has involved dancers as experts in movement-based design processes [64, 88] due to their somatic connoisseurship, either to generate new designs [64, 88] or to evaluate technology experiences, for example, inviting dancers to explore the sonic affordances of an art installation [32]. We build on, and extend, these works by inviting dancers as expert movers that can elicit nuanced evaluations of wearable technology.

3 PROTOTYPES

Four wearable prototypes were brought to the workshop: SoniBand, SoniShoes, Joakinator, and Vibrants. These were already functioning prototypes that had been previously developed in other contexts, and that were brought to this study for their capacity to provide

Figure 1: SoniBand on the left panel, depicting its technical elements and an example of wear with an angular movement sequence that would activate it. SoniShoes on the right panel, depicting its technical elements and an example of wear on the feet.

sound (SoniBand, SoniShoes and Joakinator) and haptic (Vibrants) feedback to different movement dynamics. SoniShoes and Soniband were selected for the study due to their *capacity* to alter body perception, demonstrated in prior work to which we refer to in the next subsections. Joakinator and the Vibrants were selected so as to study their *potential* to alter body perception, which at the time of this writing, no user studies had done. Each of the three sonification prototypes has a larger sound bank but for each, we selected two sounds to test - one continuous and one discrete - to allow for exploration of different sound types. The prototypes were designed to be deployed in complex movement-centric contexts, such as everyday movements, physical activity or performance arts. Hence, they were designed to be comfortable and easy to use. They could be worn in different body parts, that can be decided by participants.

3.1 SoniBand

SoniBand [62] (Fig. 1, left panel) is a wearable designed for real-time sonification of movement angles, through a range of movement-generated sounds. Embedded in a patch of fabric in a bracelet, it can be worn in various locations (e.g. arm, leg). Soniband integrates a BITalino R-IoT embedding a 9-axis Inertial Motion Unit (IMU) [1]. The R-IoT transmits movement angle data wirelessly to a Raspberry Pi Zero, which is controlled using a web browser. The device registers the minimum and maximum angle of the body part (calibration), and then it sonifies the movement angle.

Sound Conditions. Two sound conditions were brought to the workshop. We chose one to be continuous and the other discrete, as we believed that this physical characteristic of sound could elicit different effects, based on previous findings [62]. The first was "water", a sound of continuous running water throughout the movement, with an added "splash" sound of hitting water just after the start/end position of the calibrated movement. The second sound was a discrete "mechanical" sound that emulates rusty gears, and that plays throughout the movement and changes its frequency gradually as it gets near the start/end position of the calibrated movement. For further details on these sounds see [62].

Context and Prior Work. Soniband was developed with the aim of examining the impact of metaphorical movement sonifications (e.g. water, wind, mechanical sounds) on body perceptions [62]. The effects of five distinct sonifications offered by Soniband in promoting physical activity have been investigated in physically inactive and physically active populations [62], in a study exploring SoniBand in the context of functional exercises (e.g. squats, leg stretches). Results showed that the sound metaphors led to alterations in body perception (e.g., feeling strong) and quantity and quality of physical activity (e.g., do more squats) in both populations.

3.2 SoniShoes

Sonishoes [61] (Fig. 1, right panel) are footwear incorporating movement sensors that facilitate real-time sonification of foot movements, including those generated during walking. This design includes a range of movement-generated sounds. Sonishoes consist of a combination of soled sandals attached to straps, one for the left foot and one for the right, each equipped with two Force Sensitive Resistors (FSRs). Additionally, a pair of bands worn on the left and right ankles each incorporate a BITalino R-IoT, which contains an IMU. The R-IoT transmits sensor data wirelessly to a computer running Max/MSP software, which then sonifies the received sensor inputs. **Sound Conditions**. Two sound conditions were brought to the workshop. Like for SoniBand, we chose them so one would be continuous and the other discrete [62]. The first was continuous "wind" sound, a sample of a sound of actual wind modulated by the sensor signals. Inputs from the front FSRs and accelerometers are mapped to this sound, which plays during the foot swing of a stride (the lower the FSR value, the lower the audio volume). The second sound was a discrete "can crush" sound, which imitates the sound of pressing an aluminum can against the ground [16]. In the case of this sound, the FSR maximum values are mapped to varying mean audio volume (the lower the FSR value, the lower the audio volume). For further details, see [61].

[1] Technical description available at https://ismm.ircam.fr/riot/ Technical implementation available at https://github.com/BiT-BTE/SoniBand-SoniShoes-IML

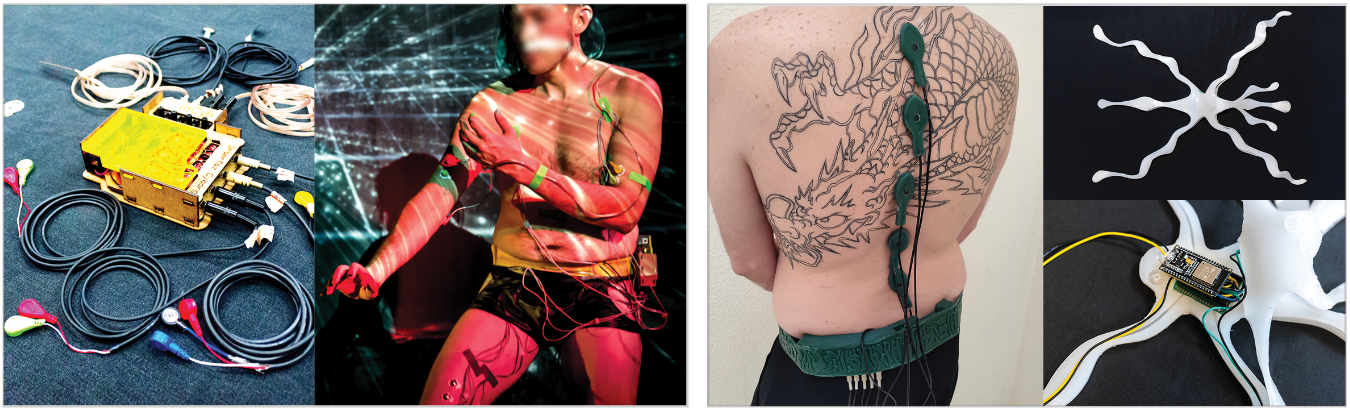

Figure 2: Joakinator on the left panel, depicting its technical elements and a still from an artistic performance where it was worn and used. Vibrants on the right panel, first the wearable version placed on a person's back as in the study, and the object version.

Context and Prior Work. SoniShoes were designed to alter body perceptions through sonification of gestures and sounds. A previous quantitative and controlled study showed that they can alter bodily sensations, affective states, and movement patterns through metaphorical movement sonification during two physical exercises: walking and thigh stretch [61]. In particular, the study found that the wind sound made participants feel more in control and less tired, while the can crush sound made them feel heavy and tired, but also more flexible (see [62] for a more detailed account).

3.3 Joakinator

Joakinator is a wearable interactive interface that integrates an Arduino, three muscle-tone EMG sensors, four FSRs, and machine learning algorithms for sonifying muscle tone and force. The software includes interfaces for communication and sonification programmed with Processing and Max/MSP [2]. The interaction design is tailored to each project and based on machine learning algorithms facilitated by the Wekinator software [33, 34]. The seven sensors can be placed in different locations on the body and it is possible to select and use a subset of them. We used three EMG sensors due to time constraints and to focus on muscle engagement.

Sound Conditions. Two sound conditions were brought to the workshop as in the other sonic prototypes, one chosen to be continuous and one to be discrete, and to be different from those in SoniBand and SoniShoes. One was an "electric" continuous sound of electricity buzzing, which frequency and volume increase with a higher muscle engagement. The other and a discrete "musical notes" MIDI sound, generated through a stochastic algorithm using the Real Time composition Library from Karlheinz Essl [29], and through Ableton Live's virtual synth. In the study, two of the EMG sensors were generating a different note each, and the third sensor was controlling the volume (velocity of the MIDI note).

Context and Prior Work. Joakinator was initially developed in the context of an art-based research endeavor [26] examining the interconnections between technology, body and performing arts, through an art-based research methodology. It has been used in 5 different projects encompassing 13 performances in different artisticfestivals. In prior work, the artist found that Joakinator mediated his relationship with the sound material, and that its direct control with the muscle tone generated a new point of exploration of the sound and muscle tone[26].

3.4 Vibrants

The Vibrants (Fig. 1, right panel) are two haptic actuation devices, a wearable version and an object version. The wearable version consists of five mini-motor discs, an adjustable waist belt with a microcontroller, and a band with a BITalino R-IoT IMU. It provides vibrotactile feedback based on body movement (angle changes) and can be worn in different locations. The R-IoT sends sensor data to a computer running Max/MSP software, which activates the feedback in response [3]. The wearable version provides linear feedback that activates bottom-to-top or top-to-down sequences, during upward and downward movements respectively. The object version is made of silicon. It has a simpler array of vibrating mini-motor discs, controlled through an app. The feedback can be configured in various patterns and speeds.

Haptic Conditions. The prototype design and haptic stimulation were based on a design concept developed during a previous workshop on designing wearables to facilitate physical activity [107]. This concept aimed to provide sensory feedback on body movement during exercise by delivering vibrations to the back, which, in turn, could elicit sensations of being 'pulled,' thereby facilitating the exercise. Two versions of this concept were created: a wearable one and an object-based one, with the intention of exploring different interactions. **Context and Prior Work**. The object version's design idea was developed on the basis of a design workshop exploring sensory feedback to alter body perception [107]. This workshop surfaced the possibility of applying vibrotactile feedback as a way to correct posture and facilitate people's inner drive to move during physical activity. The wearable version

[2]Technical description and implementation available at https://github.com/BiT-BTE/JK-BiT

[3]Technical description and implementation available at https://github.com/BiT-BTE/tectonica-haptic-sound-movement

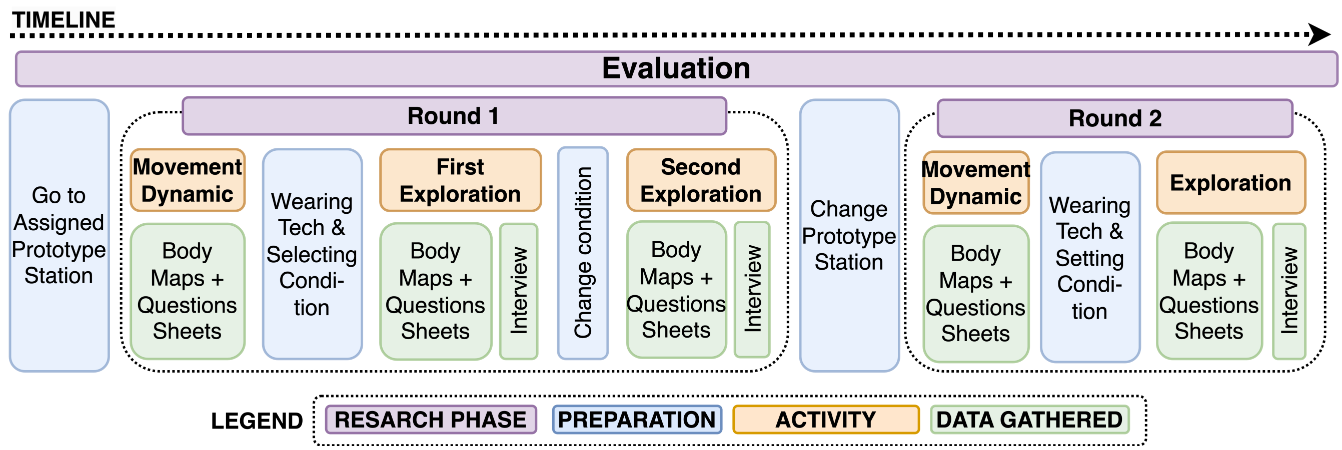

Figure 3: Visual summary of the evaluation phase of the workshop, detailing the activities that took place in a chronological manner.

of Vibrants was later designed to provide interactive vibrotactile feedback triggered by the wearer's movements.

4 METHODOLOGY AND METHODS

This paper is part of a larger study that examines the impact of interactive sensory technology on people's body perceptions. This study in itself is situated within the larger project *BODYinTRANSIT*, that ultimately attempts to design technology that can improve people's perceptions of their own body size, shape, appearance or capabilities — whenever they experience them as negative, or unfavorable. The larger study involved various design research activities, including questionnaires and workshops to understand their body perceptions; design activities and workshops to generate novel ideas for future prototypes; and a final workshop to evaluate the potential of already existing prototypes to alter body perception. This paper reports on this final workshop, which falls within interaction design research. We used a Research through Design (RtD) approach in the larger study and in the workshop[38]. RtD is centered on the generation of design knowledge through the process of designing artefacts, and through using the emerging design artefacts. While engaging in constructive design activities leading to the development of design artefacts often seen as typical application of constructive RtD [35], the fundamental practice of RtD, which involves utilizing design artefacts and methods to explore situations, problems, and gain insights [57], can be applied and shape the full research endeavor, including evaluations [38]. In our workshop, we focused on using existing and functional prototypes to probe and examine their impact on the dancers' body perception, as well as to derive design knowledge regarding the experiential characteristics of interacting with this type of technology.

Participants. Potential participant dancers were reached through our lab's contacts in professional dance and dance teaching contexts, who distributed it in their networks. To be included, dancers had to be either working professionals or in graduate professional dancing programs. In addition, and due to BODYinTRANSIT's focus on ultimately designing technology to improve people's experienced negative or unfavorable body perceptions, we employed the Multidimensional Body-Self Relations Questionnaire (MBSRQ), which assesses attitudinal aspects regarding body image [10]), to select participants that scored to be susceptible to such negative body perceptions (e.g. feeling dissatisfied regarding the own body image, or capabilities). In professional dancers, these are often due to the dual demands of optimal physical performance and adherence to an "aesthetic ideal" body image that exceeds the physical requirements of dance [76]. Although addressing body concerns was not at the focus of the present study nor workshop (which centered on body perception in general), we selected such participants so that insights from these could eventually and potentially inform future studies within the project. Nine dancers participated in the workshops (7 women, 2 men), of ages between 18 and 46 (M=27,2, SD=8,5). The study took place in Spain, a Western European country, and all participants were able-bodied. Four dancers had approximately 10 years of professional experience in dance, four others had between 2 and 7 years of experience. All had obtained, or were studying to obtain, graduate degrees in dance. Seven participants were trained in contemporary dance, one in classical dance, and one in improvisation dance.

Workshop's Structure. The workshop was run in a large, empty room at [University's]. It lasted 3h, and it was facilitated by the authors of this paper. The whole workshop was filmed with several Go-Pro cameras. The workshop started with a 30' warm-up activity to sensitize participants to the movement dynamics that the different prototypes built on, e.g. angular movements (SoniBand, Vibrant-wearable); muscle tension (Joakinator); and contact with surfaces and weight shifts (SoniShoes). The main part of the workshop consisted of two parts: evaluation of the technology; and a speculative exercise to envision potential future uses and redesigns (which is out of the scope of this paper and upon which we do not report). The evaluation phase lasted 1.5 hours with four prototype testing stations and two evaluation rounds. Figure 3 provides a visual summary of the evaluation phase's structure upon which we report. Participants were divided into groups of 2-3, and each group tested two stations, one in each round (see Table 1 for an

Table 1: Summary of the evaluation phase of the workshop.

	Station 1 SoniBand	**Station 2** SoniShoes	**Station 3** Joakinator	**Station 4** Vibrants
Movement Dynamic	Angular Movement	Contact with surface, weight shifts	Muscle Tension	Angular Movement
Evaluation Round 1	Group 1 Conditions: water, mechanical	Group 2 Conditions: can crush, wind	Group 3 Conditions: electric, musical notes	Group 4 Versions: wearable, object
Evaluation Round 2	Group 3 Condition: water	Group 4 Condition: can crush	Group 1 Condition: electric	Group 2 Versions: wearable OR object

overview of the stations and participants, and the prototypes and conditions experienced in each evaluation round).

In each station, participants started by quickly re-experiencing the movement dynamic of that station, to become sensitized to the movement dynamic of the prototype. They were asked to be aware of their body perceptions and feelings while experiencing the dynamic, to allow for later comparison with the prototype use, and they filled out a sheet that included a body map and questions.

Next, the station's facilitator helped participants put on and calibrate the technology. Participants could choose where they wanted to wear the prototype, and change its location at most once during each evaluation round. This limitation was to ensure that they explored in depth the prototype in 1-2 locations, rather than rapidly changing locations at the expense of the exploration's depth. Participants were encouraged to freely move and test the prototype, noting its effects on their body perception and feelings. At this stage, participants were instructed to engage with and explore the prototypes on their own, rather than e.g. discussing it with others. After each test, participants individually and in silence filled out a sheet containing the frontal planes of a body map silhouette, as well as open-ended questions about whereas the prototype had any effect on body perception, the type of movement and sensory feedback that elicited such effect, and questions about how such effect impacted the perceived movement, emotions, self-perception and social interactions (sheet included in the Supplementary Material).

After participants filled out the sheets, researchers performed a semi-structured interview, using the sheets to further ask participants about their experience. The interview included questions about their technology wearability and use, the combinations of movements and sensory feedback that impacted them the most, the felt effects of the technology on their body perception, and the perceived reasons regarding why they felt particular effects (see list of guiding questions in the Supplementary Material). This interview was often done with each individual participant; in some instances two participants were interviewed simultaneously if both had finished their explorations.

The two evaluation rounds had differences in length and number of sound conditions or prototypes' versions tested by each participant. The first round lasted 1 hour with each participant testing both conditions or versions, while the second round was shorter (at 30 minutes) with each participant only testing one pre-selected sound condition or version. This resulted in that, by design, some conditions were explored by more participants than others.

Data Analysis. The data analyzed for the paper consisted of participant documentation (i.e. body maps and their accompanying questions, see Supplementary Material) and the video-recorded interviews. The information that the participants filled out manually in the body maps was transcribed to a spreadsheet by the first author, and the interviews transcribed. The spreadsheet rows and columns helped cross-tabulate each prototype with the effects that participants reported on the body map, e.g. on their body perception, emotions, or movements, as well as where they felt it. This data was enriched with transcriptions from the video-recordings in which participants explained why such effects took place. The spreadsheet helped structure the data. It was analyzed following an approach influenced by *reflexive thematic analysis*[12] that acknowledges that inductive analysis will be influenced by the researchers' theoretical underpinnings. The first author made an initial coding of the table data to capture interesting features and recurring effects. These codes were grouped under three overarching themes inspired by cognitive neuroscientific theories regarding what was being affected by the technology use: feelings about the body (subjective perceptions about body image, body capabilities and body awareness); feelings about the movement (subjective perceptions about movement); and emotional feelings. The initial classification was discussed and polished with the second author of the paper. Codes on these overarching themes were inductively grouped by the first author into sub-themes that captured recurring or particular experiences. The resulting themes and subthemes were discussed with two of the authors, giving place to the final empirical results that we present in the following section. On the basis of these results and the interview data, the first author engaged in a second inductive thematic analysis, this time focused on eliciting characteristics that participants experienced when engaging with the prototypes. These characteristics were discussed and polished with the rest of the authors, until we reached four characteristics that encompass experiences at a higher level of abstraction that were shared by all participants. These characteristics were grouped as the experiential quality [66–68] that we present in Section 6.2, which is constructed as a form of intermediate-level knowledge [46, 68] that stands between specific, anecdotal accounts, and broader claims of generalizability.

5 RESULTS

All the prototypes and their conditions or versions were experienced by at least 2 participants, and up to a maximum of 5. Some

Table 2: Summary of participants trying out each prototype and condition/version, and their chosen place of wear of the prototype.

Prototype	Movement Dynamic	Condition, Version	Nº of particip.	Participants and On-Body Location
SoniBand	Angular movement	Water	5	Wrist (P2, P3, P7, P8, P9); Ankle (P2, P8); Head (P3)
		Mechanical	3	Wrist (P7, P9); Ankle (P8)
SoniShoes	Contact surface	Can Crush	4	Foot (P1, P4, P5, P6); Hands (P4, P5)
		Wind	2	Foot (P1, P6)
Joakinator	Muscle tension	Electric	3	Arm, Thigh (P1, P4, P5)
		Musical Notes	2	Thigh (P1, P6); Arm (P1)
Vibrants	Angular movement	Wearable	4	Arm (P2, P3); Back (P7, P8)
		Object	3	Chest (P3, P9); Back (P2, P3)

Figure 4: Stills from participants moving with the different prototypes, from left to right: SoniBand, SoniShoes, Joakinator and the two Vibrants. Extra illustrative images can be found in the Supplementary Material

conditions were experienced by more participants than others, as summarized in Table 2. As explained in the methods section, this was due to the study design, its time constraints, and because some prototypes required of more set-up time than others (e.g. Joakinator required of cleaning the body areas where the sensors would be placed, sorting out the cables, whereas SoniBand was readily available for wear). Participants chose to wear the prototype on different body areas (see Tab. 2) and some switched locations during phase 1 of the evaluation.

Participants experienced the prototypes through different types of dance movements, each of them imprinting their own dancing styles and practices into the exploration. Figure 4 shows stills from the recorded video with participants interacting with each prototype. More illustrative stills can be found in the Supplementary Material.

Next, we describe the results of our analysis, encompassed under the three overarching analytical lenses that we derive from prior work (e.g. [60]) and theoretical underpinnings (see Section 2.1: feelings about the body, feelings about the movement and emotional feelings). We state reasons why these occurred if participants reasoned about them. These analytical lenses attempt to highlight particularly salient aspects of the body experience that are being affected, and we do not imply that they are isolated categories. In fact, a particular sensory feedback affects simultaneously various aspects of the body experience, and results are tightly connected across the analytical lenses, as we articulate throughout the results and the discussion.

5.1 Feelings About the Body

This category refers to subjective perceptions about body appearance, capabilities and awareness. All prototypes and conditions affected the dancers' feelings about their own body (see Table 3 for a summary).

5.1.1 Body Appearance. All prototypes altered how the dancers perceived their body appearance that is, their body image, e.g. whether their body felt big or small, although not in all conditions. Three prototypes (SoniBand-water; SoniShoes-can crush; and Joakinator-both) impacted the perceived **body size**: four participants (P1, P2, P4, P5) felt *bigger*, which prompted emotional feelings, as some participants "loved" it (P2) and deemed it to be "very pleasant" (P2). It also made P1 feel like it increased the possibility of expanding their body. In contrast, one participant (P5) felt *smaller* when moving with SoniShoes-can crush.

Three prototypes (SoniBand-water, SoniShoes-wind, Vibrants) impacted the perceived **body weight**. Five participants felt *lighter*, most of them when interacting with both Vibrants (P2, P3, P8). P8 connected this feeling to the vibrations he felt in the spine, which made him experience the emotional feeling of calmness: *"I believe calmness has to do with a certain body density [...] with letting the heaviness go."* Two participants felt light when moving with SoniBand-water (P3, P9), which for P9 was prompted by her wanting to *"intertwine one movement with the next, to keep generating [water] sound"* (P9). The last participant felt lighter with SoniShoes-wind (P1) reasoned it was due to the it evoking the air: *"it made me*

Table 3: Summary of the impact of each prototype on various feelings about the body. ***(Abbreviations: Configur.=configuration;Dissass.= dissassociation; Prop.=proprioception.; Wear.=wearable)***

BODY		SoniBand		Sonishoes		Joakinator		Vibrants	
		Water	**Mech.**	**Can Crush**	**Wind**	**Electric**	**Musical**	**Object**	**Wear.**
Appearance	**Size**	Big (P2)	-	Big (P1) Small (P5)	-	Big (P1, P4, P5)		-	-
	Weight	Light (P3, P9)	-	Heavy (P4, P5)	Light (P1)	-	-	Light (P2, P3, P8)	
	Configur.	-	-	Unity (P1)	-	-	Dissass. (P6)	-	-
	Others	-	-	-	-	Malleable (P1, P4)		-	Fluid (P3, P7)
Capabilities		Fluid (P3, P9)	-	Fast (P1, P5)	Agile, flexible (P1)	Strength, control (P4, P5, P6)		Less tension (P2, P3)	-
Awareness	**Being conscious**	Body (P2, P7, P8, P9)		Contact, weight (P1, P4, P5, P6)		Muscle tension, activation (P1, P4, P5, P6)		Body (P2, P3)	-
	Others	Presence (P7)	-	-	-	-	-	-	Propr. (P8)

think of an accordion, that inflates and deflates. Like you are getting full of air with the sound" (P1). Yet, two participants who felt *heavy* with SoniBand-can crush, reasoned it made them feel like they were crushing things, which increased their body weight awareness. This fostered a body image perception that P4 deemed negative or unfavorable, as she did not like it. Two particular prototypes and conditions (SoniShoes-can crush and Joakinator-musical) impacted two participants' perceived **body configuration**. With SoniShoes-can crush, P1 felt his different body parts unified: *"sometimes you feel as if your arm was a different part from your body, your legs... you feel disconnected. With this, everything is much more compacted, like a sense of unity."* (P1). In contrast, P6 with Joakinator-musical felt a disassociation of their lower and upper body, as she wore the sensors on the thighs, which made her focus and activate those muscles more. Finally, Joakinator made two participants (P1, P4) feel their body as more *malleable*, and the Vibrants-wearable made two participants (P3, P7) feel their body as more *fluid*.

5.1.2 Body Capabilities. All prototypes altered how the dancers perceived their body capabilities, although not in all conditions. A variety of effects was documented, the most widespread of which was found on Joakinator, whose both sound conditions made three participants (P4, P5, P6) feel an increase in *strength and control*, as captured by a quote from P4: *"I have felt stronger, and with more control over my body [...] I imagined that muscular tension and that made me feel strong"*. SoniShoes-can crush made some participants (P1, P5) feel as if their body was *fast*, and its wind sound made P1 feel *agile, and flexible*. Finally, The Vibrants-object made two participants' (P2, P3) feel reduced muscular *tension*; and SoniBand-water sound made two participants (P3, and P9) feel their body *fluid*, which was regarded by P3 to be to the sound making them think of water moving in different ways.

5.1.3 Body Awareness. All prototypes altered the dancers' body awareness. SoniBand, SoniShoes, Joakinator and the Vibrants-object made participants *be more conscious* of different aspects. Almost all the participants who tried SoniBand (P2, P7, P8, P9) felt it made them more conscious of their overall body, and reasoned the sounds made them *"become very aware of the movement, what repercussion [it] has on what you hear, and what repercussion it has on the rest of your body's movement" (P2).* The Vibrants-object also made most participants be more conscious of their overall body. SoniShoes made all participants more conscious about their body's exact *points of contact* with the floor. P6 reflected on this: *"if I tried to lean on the external side of the foot, it didn't sound. In the internal part, neither [...] But [when I put] the weight in the metatarsals [of the feet], the sound increases."* It also made them more conscious about rapid *weight changes* in the foot when moving, due to the sounds reacting to it very accurately. Finally, all the participants using Joakinator, experienced *muscular tension* in their body, which helped them become more aware of how to activate particular muscles; and of the type of movement dynamic that they were performing. Other effects were found on SoniBand-water, which was found by P7 to take all her attention, and therefore made her movements *"occupy a greater presence"* (P7); and the Vibrants-wearable improved one participant's (P8) *propioception* of the distance between his column and the floor.

5.2 Feelings about the Movement

This category refers to subjective perceptions about the movement. All prototypes and conditions affected the participants' perceived movement (Table 4), in particular its qualities, including feelings of movement endurance and ease, and types of movements.

5.2.1 Movement Qualities. All prototypes and conditions altered how the dancers perceived their movement qualities, which aligned to some of Laban's movement analysis descriptions of effort [1, 63]. All the prototypes except Joakinator altered the perceived movement **speed**, although feelings about how speed was affected were

Table 4: Summary of the impact of each prototype on various feelings about the movement. ***(Abbreviations: Acceler.=acceleration)***

<table>
<tr><th colspan="2" rowspan="2">MOVEMENT</th><th colspan="2">SoniBand</th><th colspan="2">Sonishoes</th><th colspan="2">Joakinator</th><th colspan="2">Vibrants</th></tr>
<tr><th>Water</th><th>Mech.</th><th>Can Crush</th><th>Wind</th><th>Electric</th><th>Musical</th><th>Object</th><th>Wear.</th></tr>
<tr><th rowspan="4">Quali-ties</th><th>Speed</th><td>Fast
(P2, P9)</td><td>Slow
(P2, P9)</td><td>Fast
(P5, P6)
Slow (P1)</td><td>Slow
(P6)</td><td>-</td><td>-</td><td colspan="2">Slow
(P2, P3)</td></tr>
<tr><th>Fluidity, Rigidity</th><td>Fluid
(P3, P7, P9)</td><td>-</td><td>-</td><td>-</td><td colspan="2">Rigid
(P4, P6)</td><td colspan="2">Fluid
(P2, P3)</td></tr>
<tr><th>Weight</th><td>Light
(P2, P3)</td><td>-</td><td>Heavy
(P4, P5)</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Light
(P3)</td></tr>
<tr><th>Others</th><td>-</td><td>Calm (P9)</td><td>-</td><td>Agile
(P1)</td><td>-</td><td>-</td><td colspan="2">Controlled
(P2, P3)</td></tr>
<tr><th colspan="2" rowspan="2">Types</th><td rowspan="2">Twists,
acceler. (P9)
Ondulate (P2)</td><td rowspan="2">Straight
lines (P9)</td><td rowspan="2">Jumps, steps,
drag (P4)
Imbalance (P6)</td><td rowspan="2">-</td><td colspan="2">Constrained (P6)</td><td rowspan="2">Still
(P3)</td><td rowspan="2">Planes
(P7, P8)
Ample
(P3)</td></tr>
<tr><td>Small
(P1)</td><td>Ample
(P1)</td></tr>
<tr><th colspan="2">Endurance</th><td>Pushed (P7)
Do more (P9)</td><td>-</td><td colspan="2">Do more
(P1, P6)</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><th colspan="2">Ease</th><td>Easier
(P2, P7)</td><td>-</td><td>-</td><td>-</td><td colspan="2">Easier (P5)</td><td>-</td><td>-</td></tr>
</table>

very polarized: four participants felt that their movements were *slower* when moving with the Vibrants (P2, P3), SoniShoes-wind (P6), SoniShoes-can crush (P1), and SoniBand-water (P2, P9). For SoniShoes-can crush, one participant (P1) reflected this was because he focused on paying attention to the small movements of their feet. For the Vibrants, P1 reasoned they felt the vibration guided them better if they moved slow. In contrast, four participants (P2, P5, P6, and P9) felt their movements were *faster*: with SoniBand-water (P2, P9), because the metaphor of water brought about dynamism (P2, P9); and with SoniShoes-can crush (P5, P6) because they "*liked the sound and wanted to move fast so it kept playing*" (P6).

All the prototypes except SoniShoes altered the perceived movement **fluidity or rigidity**. SoniBand-water and the Vibrants made four participants feel that their movement was more *fluid*. With SoniBand-water, participants linked this to the continuity of the movements that the water sound prompted (P9), and to how this sound evoked water imagery, such as feeling *"you were getting into the water"* (P7). A participant emphasized this evocative power of being in the water: *"it was not that it made me feel like I was water and hence I was fluid - it is that it [made me feel] like playing with the water, that I moved it that [brought fluidity to the movements]"* (P2). In contrast, Joakinator made half of the participants who tried it feel that their movements were more *rigid*, because *"to make the sound play you need to tense the muscle [...] [which makes my movements] more limited, as if I have more rigidity"* (P6).

All the prototypes except Joakinator altered the perceived movement **weight**: Two participants (P2, P3) felt that their movements were *lighter* with SoniBand-water and Vibrants-wearable. With SoniBand-water, this effect was connected to the evocation of water: *"as you are listening to the water, it brings me to a much more fluid movement, a movement that is very light*" (P2). In contrast, SoniShoes-can crush made half of the participants who tried it feel heavier. P4 reflected on this: *"when we moved without the prototype, [my movements] were like very delicate, light. Now with the prototype it doesn't seem the same movement, [it has become] heavier."*

Other effects of the prototypes on movement qualities were found in SoniBand-mechanical, which was found by P9 to make her feel as if her movements were *less jerky*; SoniShoes-wind, which made P1 perceive his movement as more *agile*; and the Vibrants, which made P2 and P3 feel their movements as more *controlled*. In addition to these effects, it was found that SoniShoes and SoniBand-water affected how participants perceived their **movement endurance**, that is, their willingness and motivation to move. SoniShoes made half of the participants who tried it want to *do more*: to not wanting *"stop moving"* (P1) and to *"move [her] body more"* (P6), so she could see how the sound changed. That was shared with SoniBand-water, which made one participant want to do the movement more times because she found that the sound *"invited [her] to keep exploring"* (P9) and it was *"addictive, it makes you want to keep listening to it"* (P9). With this sound, P7 felt as if the sound prompted and guided her movement.

Finally, SoniBand-water and Joakinator made some participants (P2, P5, P7) feel that their movements became **easier** when interacting with these prototypes, giving them a greater ease of movement. For SoniBand, that was attributed to the water metaphor, and for Joakinator, because it made P5 more aware of her muscle tension, which in turn helped her control it more and move more easily.

5.2.2 Types of Movements Fostered. All prototypes and in all except one sound condition (SoniShoes-wind), fostered certain kinds of movements in the dancers, as perceived by the participants. SoniBand-water invited one participant (P9) to do movements with *acceleration*, with *twists and twirls*, so as to trigger the sound; and another (P2) to alter her rectilinear and angular movements to more *undulating* ones, due to evocations of water: *"it brought me to a movement more of water [...] it made me focus on that image that got into me, of me playing with water"* (P2). In contrast, the *mechanical* sound fostered more "robotic" movements featuring straight lines (P7, P9), which was associated to an evocation of mechanical elements: *"I felt like I was a robot [...] mechanical, automatic"* (P7).

Table 5: Summary of the impact of each prototype on various emotional feelings. ***(Abbreviations: Overwh.=overwhelming; Determ.=determination)***

<table>
<tr><th rowspan="2">EMOTION</th><th colspan="2">SoniBand</th><th colspan="2">Sonishoes</th><th colspan="2">Joakinator</th><th colspan="2">Vibrants</th></tr>
<tr><th>Water</th><th>Mech.</th><th>Can Crush</th><th>Wind</th><th>Electric</th><th>Musical</th><th>Object</th><th>Wear.</th></tr>
<tr><td>Pleasure, Well-being</td><td colspan="2">Pleasant (P7, P9)
Joy (P7)</td><td>Pleasant (P1)</td><td>Euphoria Joy, (P1)</td><td>-</td><td>-</td><td colspan="2">Pleasure
(P2, P3, P7, P8, P9)</td></tr>
<tr><td>Calmness, Relax</td><td>-</td><td>Calm (P9) Restless (P8)</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">Calm (P2, P8)
Relaxed (P7, P8, P9)</td></tr>
<tr><td rowspan="2">Negative</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">Apathetic, sad, lazy (P4, P5)</td><td rowspan="2">-</td><td colspan="2">Frustration (P6)</td><td>-</td><td>-</td></tr>
<tr><td>Overwh., Shame (P1)</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td rowspan="2">Others</td><td rowspan="2">Free (P2)
Amusing, Curious (P3)
Empowerment (P3)</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td><td colspan="2">Empowerment (P4, P5)</td><td rowspan="2">Non-surprise (P9)</td><td rowspan="2">Surprise (P7)</td></tr>
<tr><td>-</td><td>Determ., Clarity (P1)</td></tr>
</table>

SoniBand-can crush prompted an exploration of different ways of being in contact with the floor, such as *jumps, steps, and dragging the feet* (P4); and movements that involved weight changes, such as *imbalances*, oscillating movements and alternating of the hands as points of contact (P6).

Joakinator prompted constrained movements, given the perceived limitation that Joakinator brought *"I do not allow myself to do the movements I would like to, with the amplitude I would like to"* (P6) due to increased muscle tension. The electric sound was disliked by one participant (P1), who considered it elicited to him negative emotional feelings, as it made him want to do *smaller movements* to not hear the sound much. However, the same participant made *ample*, big and direct movements with the musical notes, a sound he reported to like. Finally, the Vibrants-wearable fostered movements that would trigger the vibration: P8 wearing it on the back, engaged with fast movements, up and down, and explorations on the sagittal plane, forwards and backwards. To P3, the wearable fostered ample leg movements, *"as a hinge [...] trying to articulate the maximum and minimum angle"* (P3). In contrast, the Vibrants-object version helped P3 not to move, to be *still*, which in turn prompted in her the emotional feeling of calmness she experienced: *"it brought me to something more like to muscle relax [...] rather than to explore movements with it."*

5.3 Emotional Feelings

This category refers to felt emotions. All prototypes and conditions affected the emotional feelings of the participants (see Table 5 for a summary), in particular pleasure/well-being, calmness/relax, emotions that participants reported as being negative or unfavorable, and other emotion-related aspects.

5.3.1 Pleasure, Well-being. All the prototypes except Joakinator were found to foster pleasure and emotions linked to psychological well-being. In particular, all the participants interacting with the Vibrants experienced *pleasure* and pleasant sensations, that made them "feel better" (P2). Similarly, two participants (P7, P9) described feeling **pleasure and well-being** when interacting with SoniBand-water, which they connected to evocations of the water and the real water's fluidity: *"it was due to the pleasure that water is for me: its lightness, its fluidity. It was like introducing myself in an atmosphere"* (P7). One participant (P1) felt that SoniShoes-can crush was pleasant because it helped him become aware of small movements. Two participants felt *joy* when moving with SoniBand-water (P7) and with Sonishoes-wind (P1).

5.3.2 Calmness, Relax. All the participants who experienced the Vibrants felt *calmed or relaxed*. P8 connected this calmness with the body feeling of letting go of a perceived body weight, but also to the vibrations providing a kind of a massage fostering a sensation of physical tranquility. SoniBand-mechanic sound prompted opposite feelings about **calmness and restlessness** to different participants: P9 experienced calmness when moving, as she perceived her movements to have become slower; in contrast, P8 experienced restlessness due to the body-sound relationship and how *"culturally we have associated certain sounds to certain sensations, [...] and I could not settle, or embody, or evoke a sense of calmness with this sound. [The mechanical sound] did create friction in that regard"* (P8).

5.3.3 Negative Emotions. Here we consider "negative emotions" as those explicitly reported as such by our participants, as it is a very subjective appraisal that they often made in basis to individual experiences and sociocultural associations. SoniShoes and Joakinator prompted emotions to four participants that they deemed negative. SoniShoes-can crush made P4 and P5 feel apathetic, sad and lazy. P5 connected this feeling to heaviness, the body feeling she experienced: *"that feeling of heaviness it is not something that I associate with joy"* (P5). One participant (P6) felt that Joakinator arose dual feelings. On one hand she felt *frustration*, as she felt that the prototype prompted a muscle tension that she perceived as limiting her movement; but at the same time, it made her activate and warm up those muscles, which she felt would help having a positive impact in subsequent movements: *I am frustrated by this limitation, but I know it has an objective [warming up the muscles] that will allow me to move as much as I want"* (P6). Finally, Joakinator-electric made one participant (P1) overwhelmed and ashamed by the emitting sound, which he disliked, and made him feel self-conscious; he felt embarrassed that others would see and hear him.

5.3.4 Others. Three participants felt *empowerment* when interacting with SoniBand-water and Joakinator. For Joakinator, P4 and P5 connected it to body feelings, as they felt they were more aware of how to activate the muscles and of their muscle capacity. For SoniBand-water, it was also due to the body feelings of control, because *"I moved the water and controlled what was sounding, so there was an element of 'I choose.' [I experienced] power, because I was deciding both my movement and the sound"* (P3). SoniBand-water also made P2 felt *free* when moving, while P3 felt *amusing, and curious.* The two Vibrants fostered different emotions related to *surprise*: the wearable version brought expectation and surprise to P7: *"[the prototype] makes me be surprised, and this same sensation is the one that takes me to a place I was not expecting to reach"* (P7). In contrast, the object was deemed to be unsurprising, given its lack of feedback-loops: *"you get used to the vibration [...] you normalize the vibration"* (P9). Finally, P1, felt that Joakinator-musical fostered positive feelings of *"determination and clarity"*, because it was a sound that he liked.

6 DISCUSSION

Here, we summarize the prototype's effects on the dancers' body perception in our workshop. We articulate our main contribution, the experiential quality of *Body Transformation* by presenting its four characteristics. Finally, we reflect on the methodological elements and limitations of our study and end by discussing the novelty and contributions of our work.

6.1 Prototypes and Their Effects

Our findings reveal that each prototype transformed how dancers perceived their body (see section 5.1), movement (see section 5.2) and emotions (see section 5.3). **SoniBand** impacted the perceived body size, weight, capabilities, and awareness. It also impacted movement speed, fluidity, weight, and endurance and fostered particular types of movements. It brought people pleasure and joy and made them feel free, amusing, curious, and empowered. Contrasting with prior insights [62], the water sound also made people feel more fluid [62], but it made people perceive movement as faster (instead of slowing down their pace) and did not have an effect on calmness [62]. Similarly, the mechanical sound increased body awareness [62] but it had no effect on body weight or movement endurance as in [62].

The **SoniShoes** prototype impacted the perceived body size, weight, configuration, capabilities, and awareness. It also impacted the perceived movement speed, weight, agility, and endurance and fostered particular types of movements. It gave dancers pleasure and made them feel euphoric, but also apathetic, sad and lazy due to an increase in perceived weight. The can crush sonification condition made participants feel heavier, which substantiates previous insights [61], but contrasted with those by not making people feel tired. These differences may be linked to the different populations (ours targeting dancers; prior works inactive populations), as prior works showed differences among different populations [62]. Our work also substantiates the evocative potential of SoniBand and SoniShoes' [61, 62].

The **Joakinator** impacted the dancers' perceived body size, malleability, configuration, capabilities, and awareness. It also impacted the perceived movement rigidity and amplitude and was experienced as constraining of movements, which brought about feelings of frustration and being overwhelmed, but also of empowerment due to increased muscle tension, and determination. As in [51, 118], the EMG sonification increased the focus and awareness of movement.

Finally, the **Vibrants** impacted the perceived body weight, body fluidity, and capabilities. It also increased the dancers' awareness of their body and proprioception, like other haptic technologies (e.g. [4, 5, 49, 53, 106, 123, 132]). It also impacted the movement speed, fluidity, and weight, and made movements feel more controlled. In terms of emotions, it brought pleasure, calm and relaxation.

6.2 *Body Transformation*: An Experiential Quality of Sensory Feedback for Altering Body Perception

Experiential qualities tend to characterize, reflect, and evaluate experiences with technology [46, 66–68]. *Body Transformation* as an experiential quality characterizes the participant's perceptions and experiences of their own body when interacting with sensory feedback wearables for altering body perception. The term "transformation" here highlights: 1) the *transformative potential* [106] of these technologies to alter the participant's body experience and perception in fundamental ways; and 2) a holistic understanding of the different components (perceptual and attitudinal), which manifests in interrelated alterations in behavior, emotional state and self-perception. Experiential qualities [46, 66–68] often present analytical insights related to the experience, which can be used analytically, to understand and evaluate similar technologies; and generatively, to delineate a "preferred state" [134] to aim to in the design process. Here, we do so through the particular *characteristics* of Body Transformation as experiential quality, which were derived from our evaluation. We connect each characteristic to our empirics, theory and prior work. For each characteristic, we also provide open, preliminary and high-level *design inspirations* that could be useful for fostering future generative work in related body transformation technologies and experiences. In particular, they can help others in delineating a "preferred state" [134] and draw design directions to aim towards in the design process.

6.2.1 Perceptual Transformation. The experiential quality encompasses a transformation of the body perception - rather than of the fleshy body itself. That is, while the technology does not change the actual body capabilities or appearance themselves, it affects the perception that a person has of them. This is due to the high plasticity of body perception, and its capacity to be altered through spatiotemporal multisensory mechanisms [11, 117]. In a sense, this body transformation acts as an *illusion*, like those reported in the context of neuroscientific studies on body perception (e.g. [11, 55, 108, 129]). Participants in our study reported feeling a plethora of alterations in the perception of their body appearance and capabilities, e.g.: alterations in their perceived size, weight, or feeling more/less agile or strong - without actual changes really taking place. The fact that this transformation is "merely perceptual" does not make its effects less meaningful or impacting for the participants. This is illustrated by the alterations in the participants' emotions and attitudes towards themselves, and the types of movements and explorations that each prototype prompted.

Design Inspiration: Future generative design explorations should consider fostering a transformation of body perception rather than the actual body, which as shown through our empirics, can still have a profound impact on people. Towards this, it could be beneficial to employ sensory technology providing feedback on particular body parameters. Providing feedback on singular parameters may suffice to foster perceptual transformations, for example, feedback on movement and muscle tension served to trigger holistic changes in body perception in our work. Cognitive neuroscience research (e.g. sources in Section 2.1 and related literature) provide ample theoretical knowledge and cumulative empirical proof of how particular sensory feedback can transform body perception. For example, altering the frequency of footstep sounds transforms the perceived body weight, gait, emotional state, and body capabilities [19, 109, 114]. This body of work can serve as anchor and departure point for future design ventures.

6.2.2 Holistic Transformation. Body Transformation as experiential quality encompassed a holistic transformation of the body perception, including alterations in perception of body capabilities [59, 70], and of body image [24, 65], in both their perceptual and attitudinal components [22, 112]. Each prototype fostered alterations on bodily, movement and emotional feelings, which collectively transformed our participants' body perception. Although theoretically, it is still unclear how various components are linked, and interact with each other [22, 41], our empirical work shows the interconnectedness of these components as reflected by our participants' answers, for example: connecting alterations in perceived body appearance to particular emotional feelings (e.g. P2 with SoniBand-water felt that her body was bigger, which she "loved" and deemed to be "very pleasant" by P2); or connecting alterations in body awareness to alterations in movement qualities (e.g. P1 with SoniShoes-can crush said he perceived their movements as slower because he was paying attention to the small movements of his feet). Body and movement feelings were often intertwined with emotional feelings in culturally-specific ways: for example, SoniShoes-can crush made some participants feel heavier and thus apathetic, sad and lazy due to sociocultural body ideals. Our experiential quality is characterized by this holistic view of interconnected components of body perception through technology use.

Design Inspiration: Future generative design explorations should consider that a body transformation technology might elicit effects on a variety of different, intertwined components of body perception, that is e.g. feelings about the body, movement and emotional feelings. Our work has shown that these components are experienced as tightly intertwined, and that e.g. particular feelings about the body can trigger particular emotional responses. Design endeavours should therefore address body perception in holistic terms. Further, future research should consider that the individual and sociocultural contexts will shape the body transformations that take place.For example, in our work participants often associated an increase in perceived body weight to emotions they deemed negative, but this may change across cultures and population groups. It is important that future work acknowledges the sociocultural contexts of their designs in order to elicit rich, nuanced and contextually relevant body transformation experiences.

6.2.3 Evocative Power. The effects of Body Transformation often relied on the technology's capacity to evoke imagery, memories, metaphors and body ideals in the participants. Sonification has been found to have this evocative capacity (e.g. [58, 61, 62]), and in our study this was particularly common in SoniBand-water sound, resonating with prior work [62]. In our study, different participants attributed their perception of feeling more fluid, faster, lighter, easier to imagery evoked by the water sound: of being in the water, or getting into the water. Other sound conditions also had evocative power, e.g.: SoniBand-mechanical fostered "robotic" movements for their association to robots, and feeling mechanical and automatic - which aligns with other "robotic" sounds [58]. SoniShoes-wind evoked to some participants imagery of air, of being inflated and deflated, making them feel lighter. Finally, SoniShoes-can crush made some participants feel heavier as they felt they were crashing things using their weight, which sometimes evoked a perceived cultural body ideal that the specific participant considered negative (i.e. "heavier body"), which in turn prompted emotions that participants considered negative (apathy, sadness, laziness). We can see how social and cultural pressures regarding ideal body appearance in Western and global-north societies [119] and an individual's personal experiences with sound that evoke expectations [82]) have effects on the body perception mediated by sound. We see these individual and sociocultural effects on previous research that demonstrated that sound feedback can lead to varying body perceptions based on factors such as body weight aspirations [114].

Design Inspiration: Future generative design explorations should consider that particular sensory feedback may evoke sociocultural associations between the body and the technology, and that this association will be highly dependant on sociocultural associations, which can be also very subjective and not easily transferrable. Hence, explorations into body transformation technologies should simultaneously take into account the spatiotemporal multisensory mechanisms being targeted, but also the evocative power of different sensory inputs, so as to design the sought transformative experiences. For example, future design ventures could take an approach where targeted sensory feedback modalities are explored for their evocative power (e.g. what particular naturalistic or synthetic sounds evoke for particular populations) prior to designing a prototype.

6.2.4 Transformation Valuations. Body transformation technologies are not neutral artefacts (as neither are other technologies [30]). They actively shape body perception, which shapes the attitudes that people will have towards the technological experience itself. The final characteristic of the experiential quality is its attitudinal component: the subjective valuations that participants made in regards to the transformation itself. The prototypes mostly had effects that our participants deemed positive or favorable on body perception, such as an increased body awareness, improved body capabilities and appearance, creative movement exploration, ease of movement, and positive emotions. Participants reported experiencing positive effects from the transformations fostered by the wearables, yet there were also several instances where the participants considered a transformation to have a negative impact, such as when it prompted what they considered to be negative emotions or when it affected their body perception in ways that they deemed unfavorable. These less desirable experiences were often linked to social and culture norms and pressures on body perception, such as sociocultural body ideals (e.g. feeling heavier with SoniShoes-can crush) or perceived movement limitations (e.g. feeling constrained when moving with Joakinator). Hence, the valuations of particular feelings about the body or movement were sociocultural specific and individual - depending on a person's lived experience.

Design Inspiration: Future generative design explorations should keep in mind that a transformation will never be neutral: it will be valuated by individuals as positive, negative, or something different altogether, and possibly differently by different people. This is potentially due to the very subjective experience that people have of their own bodies, as well as individual and sociocultural factors that shape body perception. Such individuality may call for designs that are open and flexible enough to accommodate different feedback interpretations and valuations, towards providing individualized experiences that are relevant to individuals. In that regard, recent works employing open-ended feedback have demonstrated the capacity of such technologies to accommodate a range of meaningful experiences across different individuals [62, 126, 127]. Finally, in future, less exploratory, design work, a sought valuation probably would need to align well with the goals of a research project and values of the designers. As such, we recommend to consider this variety of valuations early in a design process with relevant stakeholders.

6.3 Methodological Reflections, Limitations and Future Work

In our work, we invited dancers as expert study participants for wearable technology prototype testing, exploring their unique relationship to their own body perception and movement as mediated by the perception altering prototypes. As somatic connoisseurs [88], they had the ability to access their feelings about their body and movement, both verbally and non-verbally, in a deep and nuanced way. Their expertise did not only encompass proprioceptive acuity [48] or heightened action-perception links and movement control [9], but also the capacity to attune to their own somatic knowledge to identify and articulate body perception changes. This proved central in the evaluation of our sensory technologies. Further, they had the capacity to articulate nuanced and elusive aspects of their somatic experience, and we were humbled by their generosity in sharing with us researchers and other dancers very intimate feelings.

We contend that, in our work, inviting dancers did indeed support a nuanced evaluation of our prototypes - in the context of their dance explorations and own body perception. As such, methodologically they brought an invaluable contribution to our work. This approach of inviting dancers into the design process resonates with prior work [64, 88], and extends those with a proposal to invite them not only during the early, generative phases of designing, but also as expert study participants that can support rich evaluations of wearable and sensory technology.

Limitations and Future Work. Our study aimed to identify the effects of the wearable prototypes on body perception, but not map particular feedback characteristics to particular effects. Further studies are needed to understand what characteristics cause each transformation and derive more concrete design inspirations, e.g. in the form of design guidelines and/or requisites. Like previous experiential qualities [66–68], ours is provisional, "intended for other designers to appropriate [...] and to elaborate and modify drawing on their own experience" [66] with technology for altering body perception, in particular, wearables.

Our results are based on a single three-hour workshop with nine dancers using four wearable technologies. While smaller sample sizes are commonplace in RtD processes that aim at eliciting rich and nuanced qualitative accounts [57], the limited exposure to the technology (i.e. three-hour workshop, each participant experienced two of our four prototypes) means that our empirical results should be taken as preliminary. Further, our work centered on only professional dancers. As such, future work with more participants should be done to establish the recurrence of our results or to explore if similar transformations occur in other, non-specialist communities. Similarly, future evaluative work is needed to explore the experiential quality's potential to cut across different situations, populations and prototypes. In particular, there is need for future work that explores and applies the design inspirations through constructive design work, and through this work concretizes them into more detailed and actionable design recommendations, e.g. in the form of design guidelines and/or requisites.

A related point is that our study is based on a single encounter with the technology. This is common in studies of sensory technologies for perception and in soma design research (e.g. [6, 17, 49, 59–61, 87, 104, 109, 114, 129]), in which only a few studies look at the impact over longer periods of time (e.g. [28, 62, 98, 106]). A next step of the work would be to study the impacts over longer time frames.

Further, future studies in everyday ubiquitous contexts should address explicitly the ethics of body transformation, including the agency of designers and users in deciding such transformations. Our study used prototypes with previously set designerly intents, i.e.: to alter body perception towards better ways of experiencing the body during physical activity (e.g. SoniBand [62], SoniShoes [61], Vibrants [107]), or artistic intents, to explore the creative body in movement (e.g. Joakinator). These intents led to participants reporting experiencing both positive and negative body perceptions. It is worth noting that the study took place in Spain, a Western European country, that all participants were able-bodied, and that this somatic and cultural context shapes the results of our work (Section 5). What participants considered to be a positive or negative perception, or emotion, was often culture-specific, and might change across cultures and even groups of people. Hence, future work is also needed to understand the effects of body transformation on people situated in other sociocultural contexts, with other bodily and lived experiences.

6.4 Novelty and Contribution

Our work presents a conceptual, an empirical and a methodological contribution. Conceptually, we contribute the experiential quality **Body Transformation**, which characterizes the subjective experience of interacting with wearable prototypes to alter body perception. The quality considers a holistic transformation of body perception, considering emotional, perceptual, behavioural and attitudinal transformations. This characterization of the technology's impact contrasts to, and extends, prior studies on technologies for altering body perceptions, which have often focused on *singular* components of perception: the perceptual component (altering the perceived body size [129] or capabilities [70]); the attitudinal component (e.g. promote positive body image [83]); or a *subset* of those, (e.g. altering perceived body weight and feeling happier [109]). It also extends prior soma design works in HCI, which often have focused on body awareness (e.g. [6, 49, 53, 123]) and less on other aspects of body perception, such as perceptual or attitudinal components (with notable exceptions [106]). Our experiential quality can be used to better understand the impact of sensory feedback technologies to alter body perception, using each characteristic as analytical or evaluative lens. As it is common in experiential qualities, our characterizations could be used generatively in the design process, through developing "(design) judgment ability" among designers [66], and helping to "identify promising candidates among a set of early design concepts." [66]. And although future work is needed, we believe that our design inspirations can also be used generatively, "formulat(ing) desirable directions for concept design in early phases of a design process" [66], paving the way for project-specific requisites, or design drives to design technologies and experiences that foster similar body transformations.

Our work also presents novelty and contributions at an empirical level, with concrete insights on how each prototype affected the dancers' feelings about their body, their movement and their emotional feelings. Our insights substantiate SoniBand's and SoniShoes' capacity to alter body perception found in prior studies [61, 62], and extends these prior works in three different ways: first, with a focus on complex movements such as dancing - as opposed to prior studies featuring few concrete, and very controlled, exercises (e.g. squats, arm raises, tight stretch) in those studies. Second, with novel insights of these prototoypes' effects in a new population (dancers), as opposed to physically inactive and active people in prior work. Third, with a holistic focus on the different components of body perception, which only one of the studies [62] had touched upon, and only for one prototype (SoniBand) and very few controlled movements. Our work also contributes insights on two novel prototypes to transform body perception: Joakinator, initially developed in a art-based research endeavor and previously deployed only in artistic performances; and the Vibrants, with the object version initially developed in basis to embodied design workshops [107], but not deployed in user studies. We show that these prototypes have the capacity to alter body perception in multiple ways for different people, which contributes to the existing body of work of sensory feedback technologies to alter body perception (e.g. [7, 19, 51, 55, 60–62, 73, 77, 86, 99, 103, 105, 107–110, 113–118, 129]). In overall, these prototypes add to TEI's body of work on body technologies and interfaces.

Finally, we contribute to prior HCI work on dancers (e.g.[8, 13, 43, 52, 71, 74, 80, 121, 133]) with a novel focus on altering their body perception. Methodologically, our work shows the potential of inviting dancers as a relevant expert group to help evaluate sensory technologies. This is due to their expertise and somatic connoiseurship, and their capacity to articulate nuanced and elusive aspects of their somatic experience. Our work adds to, and extends with further empirical proof, the important, but yet limited, body of work that has proposed involving dancers as experts in movement-based design processes [32, 64, 88], with an example of how they can support nuanced evaluations of wearable sensory technology.

7 CONCLUSION

This paper explores the effects of four prototypes (SoniBand, SoniShoes, Joakinator, and Vibrants) on body perception holistically. Our findings reveal that each prototype has an impact on feelings about the body, movement, and emotions. Based on our findings, we articulate *Body Transformation* as an experiential quality of sensory feedback for altering body perception. The quality highlights the transformative potential of such technologies, as well as their impact on body perception, behavior and emotional state. This quality can be used analytically to better understand the impact of sensory feedback technologies to alter body perception. Potentially, it could also be used generatively, using our characteristics and design inspirations as departing point in future generative design endeavors that seek to foster similar body transformations. We believe that our work offers to the TEI community valuable insights and design knowledge in regards to sensory feedback prototypes that alter body perception, and methodological inspiration to support wearable testing together with dancers as somatic connoisseurs. We hope that our work inspires future designs and evaluations.

ACKNOWLEDGMENTS

This research was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 101002711; project BODY-inTRANSIT). It was also partially supported by the Spanish Agencia Estatal de Investigación (PID2019-105579RB-I00/AEI/10.13039/5011 00011033 and Programa I3); the Madrid Government under the Multiannual Agreement with UC3M in the line of Research Funds for Beatriz Galindo Fellowships (MovIntPlayLab-CM-UC3M 2021/00050/ 001) in the context of the V PRICIT (Regional Programme of Research and Technological Innovation); and Sweden's Digital Futures Research Center through a postdoctoral fellowship.

REFERENCES

[1] Sarah Fdili Alaoui, Baptiste Caramiaux, Marcos Serrano, and Frédéric Bevilacqua. 2012. Movement Qualities As Interaction Modality. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, New York, NY, USA, 761–769. https://doi.org/10.1145/2317956.2318071 event-place: Newcastle Upon Tyne, United Kingdom.

[2] Rachel Andrew, Marika Tiggemann, and Levina Clark. 2016. Positive body image and young women's health: Implications for sun protection, cancer screening, weight loss and alcohol consumption behaviours. *Journal of Health Psychology* 21, 1 (Jan. 2016), 28–39. https://doi.org/10.1177/1359105314520814

[3] Karen Anne Cochrane, Kristina Mah, Anna Ståhl, Claudia Núñez-Pacheco, Madeline Balaam, Naseem Ahmadpour, and Lian Loke. 2022. Body Maps: A Generative Tool for Soma-based Design. In *Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '22)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3490149.3502262

[4] Simon Asplund and Martin Jonsson. 2018. SWAY - Designing for Balance and Posture Awareness. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (Stockholm, Sweden) *(TEI '18)*. Association for Computing Machinery, New York, NY, USA, 470–475. https://doi.org/10.1145/3173225.3173262

[5] Mark J. Berentsen, Marit Bentvelzen, and Paweł W. Woźniak. 2021. MTBalance: Assisting Novice Mountain Bikers with Real-Time Proprioceptive Feedback. *Proc. ACM Hum.-Comput. Interact.* 5, ISS, Article 506 (nov 2021), 25 pages. https://doi.org/10.1145/3488551

[6] Ilias Bergström and Martin Jonsson. 2016. Sarka: Sonification and Somaesthetic Appreciation Design. In *Proceedings of the 3rd International Symposium on Movement and Computing (MOCO '16)*. ACM, New York, NY, USA, 1:1–1:8. https://doi.org/10.1145/2948910.2948922 event-place: Thessaloniki, GA, Greece.

[7] Frédéric Bevilacqua, Eric O. Boyer, Jules Françoise, Olivier Houix, Patrick Susini, Agnès Roby-Brami, and Sylvain Hanneton. 2016. Sensori-Motor Learning with Movement Sonification: Perspectives from Recent Interdisciplinary Studies. *Frontiers in Neuroscience* 10 (2016). https://www.frontiersin.org/articles/10.3389/fnins.2016.00385

[8] Daniel Bisig and Pablo Palacio. 2016. Neural Narratives: Dance with Virtual Body Extensions. In *MOCO*. https://doi.org/10.1145/2948910.2948925

[9] Bettina Bläsing, Beatriz Calvo-Merino, Emily S. Cross, Corinne Jola, Juliane Honisch, and Catherine J. Stevens. 2012. Neurocognitive control in dance perception and performance. *Acta Psychologica* 139, 2 (Feb. 2012), 300–308. https://doi.org/10.1016/j.actpsy.2011.12.005

[10] Luis Botella García del Cid, Emma Ribas Rabert, and Jesús Benito Ruiz. 2009. Evaluación Psicométrica de la Imagen Corporal: Validación de la versión española del multidimensional body self relations questionnaire (MBSRQ). *Revista Argentina de Clínica Psicológica* (2009). https://www.redalyc.org/articulo.oa?id=281921775006

[11] M. Botvinick and J. Cohen. 1998. Rubber hands 'feel' touch that eyes see [8]. *Nature* 391, 6669 (1998), 756. https://doi.org/10.1038/35784

[12] Virginia Braun and Victoria Clarke. 2019. Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health* 11, 4 (Aug. 2019), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

[13] Harry Brenton, Andrea Kleinsmith, and Marco Gillies. 2014. Embodied Design of Dance Visualisations. In *Proceedings of the 2014 International Workshop on Movement and Computing (MOCO '14)*. Association for Computing Machinery, New York, NY, USA, 124–129. https://doi.org/10.1145/2617995.2618017

[14] Courtney Brown. 2019. Machine Tango: An Interactive Tango Dance Performance. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. Association for Computing Machinery, New York, NY, USA, 565–569. https://doi.org/10.1145/3294109.3301263

[15] Kendall J. Burdick, Seiver K. Jorgensen, Megan O. Holmberg, Samantha P. Kultgen, Taylor N. Combs, and Joseph J. Schlesinger. 2018. Benefits of sonification and haptic displays with physiologic variables to improve patient safety. *Proceedings of Meetings on Acoustics* 35, 1 (Nov. 2018), 020001. https://doi.org/10.1121/2.0000941 Publisher: Acoustical Society of America.

[16] Baptiste Caramiaux, Frédéric Bevilacqua, Tommaso Bianco, Norbert Schnell, Olivier Houix, and Patrick Susini. 2014. The Role of Sound Source Perception in Gestural Sound Description. *ACM Trans. Appl. Percept.* 11, 1 (April 2014). https://doi.org/10.1145/2536811 Place: New York, NY, USA Publisher: Association for Computing Machinery.

[17] Daniel Cesarini, Davide Calvaresi, Chiara Farnesi, Diego Taddei, Stefano Frediani, Bodo E. Ungerechts, and Thomas Hermann. 2016. MEDIATION: An eMbEddeD System for Auditory Feedback of Hand-water InterAcTION while Swimming. *Procedia Engineering* 147 (Jan. 2016), 324–329. https://doi.org/10.1016/j.proeng.2016.06.301

[18] Matthew Clark and Afsaneh Doryab. 2023. Sounds of Health: Using Personalized Sonification Models to Communicate Health Information. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 6, 4 (Jan. 2023), 206:1–206:31. https://doi.org/10.1145/3570346

[19] Sunje Clausen, Ana Tajadura-Jiménez, Christian P. Janssen, and Nadia Bianchi-Berthouze. 2021. Action sounds informing own body perception influence gender identity and social cognition. *Frontiers in Human Neuroscience* (2021). https://doi.org/10.3389/fnhum.2021.688170

[20] Karen Cochrane, Lian Loke, Matthew Leete, Andrew Campbell, and Naseem Ahmadpour. 2021. Understanding the First Person Experience of Walking Mindfulness Meditation Facilitated by EEG Modulated Interactive Soundscape. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Salzburg, Austria) *(TEI '21)*. Association for Computing Machinery, New York, NY, USA, Article 18, 17 pages. https://doi.org/10.1145/3430524.3440637

[21] Karen Anne Cochrane, Lian Loke, Andrew Campbell, Matthew Leete, and Naseem Ahmadpour. 2020. An Interactive Soundscape to Assist Group Walking Mindfulness Meditation. In *Proceedings of the 7th International Conference on Movement and Computing* (Jersey City/Virtual, NJ, USA) *(MOCO '20)*. Association for Computing Machinery, New York, NY, USA, Article 21, 3 pages. https://doi.org/10.1145/3401956.3404240

[22] Katri K Cornelissen, Helena Widdrington, Kristofor McCarty, Thomas V Pollet, Martin J Tovée, and Piers L Cornelissen. 2019. Are attitudinal and perceptual body image the same or different? Evidence from high-level adaptation. *Body Image* 31 (2019), 35–47. https://doi.org/10.1016/j.bodyim.2019.08.001

[23] Luke Dahl, Christopher Knowlton, and Antonia Zaferiou. 2019. Developing real-time sonification with optical motion capture to convey balance-related metrics to dancers. In *Proceedings of the 6th International Conference on Movement and Computing (MOCO '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3347122.3359600

[24] Frédérique. De Vignemont. 2018. *Mind the body: An exploration of bodily self-awareness.* Oxford University Press.

[25] Frédérique De Vignemont, Henrik H. Ehrsson, and Patrick Haggard. 2005. Bodily illusions modulate tactile perception. *Current Biology* 15, 14 (2005), 1286–1290. https://doi.org/10.1016/j.cub.2005.06.067

[26] Joaquín Roberto Díaz Durán. 2022. Interfaz Ciborg. Dispositivo interactivo para reflexionar la relación arte, tecnología y cuerpo en la performance. (2022). https://ruidera.uclm.es/xmlui/handle/10578/29737 Accepted: 2022-04-26T08:45:54Z Publisher: Universidad de Castilla-La Mancha.

[27] Hesham Elsayed, Martin Weigel, Florian Müller, Martin Schmitz, Karola Marky, Sebastian Günther, Jan Riemann, and Max Mühlhäuser. 2020. VibroMap: Understanding the Spacing of Vibrotactile Actuators across the Body. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 4, 4 (Dec. 2020), 125:1–125:16. https://doi.org/10.1145/3432189

[28] Sara Eriksson, Kristina Höök, Richard Shusterman, Dag Svanes, Carl Unander-Scharin, and Åsa Unander-Scharin. 2020. Ethics in Movement: Shaping and Being Shaped in Human-Drone Interaction. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376678

[29] Karlheinz Essl. 2022. Karlheinz Essl: RTC-lib - Real Time Composition Library for Max and Pd (1992-2022) for macOS and Windows. https://www.essl.at/works/rtc.html

[30] Daniel Fallman. 2011. The New Good: Exploring the Potential of Philosophy of Technology to Contribute to Human-computer Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11)*. ACM, New York, NY, USA, 1051–1060. https://doi.org/10.1145/1978942.1979099

[31] Sarah Fdili Alaoui. 2019. Making an Interactive Dance Piece: Tensions in Integrating Technology in Art. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 1195–1208. https://doi.org/10.1145/3322276.3322289 event-place: San Diego, CA, USA.

[32] Frank Feltham, Lian Loke, Elise van den Hoven, Jeffrey Hannam, and Bert Bongers. 2013. The Slow Floor: Increasing Creative Agency While Walking on an Interactive Surface. In *Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction (TEI '14)*. ACM, New York, NY, USA, 105–112. https://doi.org/10.1145/2540930.2540974

[33] Rebecca Fiebrink. 2019. Machine Learning Education for Artists, Musicians, and Other Creative Practitioners. *ACM Transactions on Computing Education* 19, 4 (Sept. 2019), 31:1–31:32. https://doi.org/10.1145/3294008

[34] Rebecca Fiebrink, Dan Trueman, and Perry R Cook. 2009. A Meta-Instrument for Interactive, On-the-fly Machine Learning. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME'09) (NIME'09)*. 280–285.

[35] Jodi Forlizzi, John Zimmerman, Paul Hekkert, and Ilpo Koskinen. 2018. Let's Get Divorced: Constructing Knowledge Outcomes for Critical Design and Constructive Design Research. In *Proceedings of the 2018 ACM Conference Companion Publication on Designing Interactive Systems* (Hong Kong, China) *(DIS '18 Companion)*. Association for Computing Machinery, New York, NY, USA, 395–397. https://doi.org/10.1145/3197391.3197395

[36] Emma Frid, Jonas Moll, Roberto Bresin, and Eva-Lotta Sallnäs Pysander. 2019. Haptic feedback combined with movement sonification using a friction sound improves task performance in a virtual throwing task. *Journal on Multimodal User Interfaces* 13, 4 (Dec. 2019), 279–290. https://doi.org/10.1007/s12193-018-0264-4

[37] Shaun Gallagher. 2005. *How the Body Shapes the Mind.* Oxford University Press, Oxford. 294 pages. https://doi.org/10.1093/0199271941.001.0001

[38] William Gaver. 2012. What Should We Expect from Research Through Design?. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 937–946. https://doi.org/10.1145/2207676.2208538

[39] Klaske A. Glashouwer, Roosmarijn M. L. van der Veer, Fayanadya Adipatria, Peter J. de Jong, and Silja Vocks. 2019. The role of body image disturbance in the onset, maintenance, and relapse of anorexia nervosa: A systematic review. *Clinical Psychology Review* 74 (Dec. 2019), 101771. https://doi.org/10.1016/j.cpr.2019.101771

[40] Keith Evan Green. 2019. Strange Places: Loci of Design Inspiration. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. Association for Computing Machinery, New York, NY, USA,

173–180. https://doi.org/10.1145/3294109.3300998

[41] Sarah Grogan. 2021. *Body Image* (4th ed.). Routledge, London. https://doi.org/10.4324/9781003100041

[42] Tobias Großhauser, Bettina Bläsing, Corinna Spieth, and Thomas Hermann. 2012. Wearable Sensor-Based Real-Time Sonification of Motion and Foot Pressure in Dance Teaching and Training. *Journal of the Audio Engineering Society* 60, 7/8 (2012). https://pub.uni-bielefeld.de/record/2528002

[43] Carlos Guedes. 2007. Establishing a musical channel of communication between dancers and musicians in computer-mediated collaborations in dance performance. In *Proceedings of the 7th international conference on New interfaces for musical expression (NIME '07)*. Association for Computing Machinery, New York, NY, USA, 417–418. https://doi.org/10.1145/1279740.1279843

[44] Kelly S. Hale and Kay M. Stanney. 2004. Deriving haptic design guidelines from human physiological, psychophysical, and neurological foundations. *IEEE Computer Graphics and Applications* 24, 2 (March 2004), 33–39. https://doi.org/10.1109/MCG.2004.1274059 Conference Name: IEEE Computer Graphics and Applications.

[45] Aurie Hsu and Steven Kemper. 2019. The Hybrid Body and Sonic-Cyborg Performance in Why Should Our Bodies End at the Skin?. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. Association for Computing Machinery, New York, NY, USA, 547–551. https://doi.org/10.1145/3294109.3301255

[46] Kristina Höök and Jonas Löwgren. 2012. Strong Concepts: Intermediate-level Knowledge in Interaction Design Research. *ACM Trans. Comput.-Hum. Interact.* 19, 3 (Oct. 2012), 23:1–23:18. https://doi.org/10.1145/2362364.2362371

[47] Ryan Ingebritsen, Christopher Knowlton, Hugh Sato, and Erica Mott. 2020. Social Movements: A Case Study in Dramaturgically-Driven Sound Design for Contemporary Dance Performance to Mediate Human-Human Interaction. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 227–237. https://doi.org/10.1145/3374920.3374955

[48] Corinne Jola, Angharad Davis, and Patrick Haggard. 2011. Proprioceptive integration and body representation: insights into dancers' expertise. *Experimental Brain Research* 213, 2 (Sept. 2011), 257–265. https://doi.org/10.1007/s00221-011-2743-7

[49] Martin Jonsson, Anna Ståhl, Johanna Mercurio, Anna Karlsson, Naveen Ramani, and Kristina Höök. 2016. The Aesthetics of Heat: Guiding Awareness with Thermal Stimuli. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. ACM, New York, NY, USA, 109–117. https://doi.org/10.1145/2839462.2839487

[50] Stephan Jürgens, Nuno N. Correia, and Raul Masu. 2021. The Body Beyond Movement: (Missed) Opportunities to Engage with Contemporary Dance in HCI. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '21)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3430524.3440624

[51] Jakob Karolus, Felix Bachmann, Thomas Kosch, Albrecht Schmidt, and Paweł W. Woźniak. 2021. Facilitating Bodily Insights Using Electromyography-Based Biofeedback during Physical Activity. In *Proceedings of the 23rd International Conference on Mobile Human-Computer Interaction* (Toulouse & Virtual, France) *(MobileHCI '21)*. Association for Computing Machinery, New York, NY, USA, Article 14, 15 pages. https://doi.org/10.1145/3447526.3472027

[52] Pavel Karpashevich, Eva Hornecker, Michaela Honauer, and Pedro Sanches. 2018. Reinterpreting Schlemmer's Triadic Ballet: Interactive Costume for Unthinkable Movements. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, 61:1–61:13. https://doi.org/10.1145/3173574.3173635

[53] Pavel Karpashevich, Pedro Sanches, Rachael Garrett, Yoav Luft, Kelsey Cotton, Vasiliki Tsaknaki, and Kristina Höök. 2022. Touching Our Breathing through Shape-Change: Monster, Organic Other, or Twisted Mirror. *ACM Transactions on Computer-Human Interaction* 29, 3 (Feb. 2022), 22:1–22:40. https://doi.org/10.1145/3490498

[54] Konstantina Kilteni, Antonella Maselli, Konrad P. Kording, and Mel Slater. 2015. Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. *Frontiers in Human Neuroscience* 9 (2015). https://doi.org/10.3389/fnhum.2015.00141

[55] Konstantina Kilteni, Jean-Marie Normand, Maria V Sanchez-Vives, and Mel Slater. 2012. Extending Body Space in Immersive Virtual Reality: A Very Long Arm Illusion. *PLOS ONE* 7, 7 (July 2012), e40867. https://doi.org/10.1371/journal.pone.0040867 Publisher: Public Library of Science.

[56] Keina Konno, Richi Owaki, Yoshito Onishi, Ryo Kanda, Sheep, Akiko Takeshita, Tsubasa Nishi, Naoko Shiomi, Kyle McDonald, Satoru Higa, Motoi Shimizu, Yosuke Sakai, Yasuaki Kakehi, Kazuhiro Jo, Yoko Ando, Kazunao Abe, and Takayuki Ito. 2016. Dividual Plays Experimental Lab: An installation derived from Dividual Plays. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. Association for Computing Machinery, New York, NY, USA, 647–652. https://doi.org/10.1145/2839462.2856346

[57] Ilpo Koskinen, John Zimmerman, Thomas Binder, Johan Redström, and Stephan Wensveen. 2012. *Design Research Through Practice.* Morgan Kaufmann, Boston. https://doi.org/10.1016/B978-0-12-385502-2.00015-8

[58] Yosuke Kurihara, Taku Hachisu, Katherine J. Kuchenbecker, and Hiroyuki Kajimoto. 2013. Virtual Robotization of the Human Body via Data-Driven Vibrotactile Feedback. In *Advances in Computer Entertainment (Lecture Notes in Computer Science)*, Dennis Reidsma, Haruhiro Katayose, and Anton Nijholt (Eds.). Springer International Publishing, Cham, 109–122. https://doi.org/10.1007/978-3-319-03161-3_8

[59] Bigna Lenggenhager, Tej Tadi, Thomas Metzinger, and Olaf Blanke. 2007. Video ergo sum: manipulating bodily self-consciousness. *Science (New York, N.Y.)* 317, 5841 (2007), 1096–1099. https://doi.org/10.1126/science.1143439

[60] Judith Ley-Flores, Eslam Alshami, Aneesha Singh, Frédéric Bevilacqua, Nadia Bianchi-Berthouze, Ophelia Deroy, and Ana Tajadura-Jiménez. 2022. Effects of pitch and musical sounds on body-representations when moving with sound. *Scientific Reports* 12, 1 (2022), 2676. https://doi.org/10.1038/s41598-022-06210-x

[61] Judith Ley-Flores, Frédéric Bevilacqua, Nadia Bianchi-Berthouze, and Ana Tajadura-Jiménez. 2019. Altering body perception and emotion in physically inactive people through movement sonification. In *Proceedings of the 2019 International Conference on Affective Computing and Intelligent Interaction (ACII), 3rd-6th September, 2019, Cambridge, UK.*

[62] Judith Ley-Flores, Laia Turmo Vidal, Nadia Berthouze, Aneesha Singh, Frédéric Bevilacqua, and Ana Tajadura-Jiménez. 2021. SoniBand: Understanding the Effects of Metaphorical Movement Sonifications on Body Perception and Physical Activity. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM, New York, NY, USA, 1–16. https://doi.org/10.1145/3411764.3445558

[63] Lian Loke, Astrid T. Larssen, and Toni Robertson. 2005. Labanotation for Design of Movement-based Interaction. In *Proceedings of the Second Australasian Conference on Interactive Entertainment (IE '05)*. Creativity & Cognition Studios Press, Sydney, Australia, Australia, 113–120. http://dl.acm.org/citation.cfm?id=1109180.1109197

[64] Lian Loke and Toni Robertson. 2010. Studies of dancers: Moving from experience to interaction design. *International Journal of Design* 4, 2 (2010). http://search.proquest.com/openview/65d82e8ef58af379e1e881cdf45114b6/1?pq-origsite=gscholar

[65] Matthew R. Longo and Patrick Haggard. 2012. What Is It Like to Have a Body? *Current Directions in Psychological Science* 21, 2 (2012), 140–145. https://doi.org/10.1177/0963721411434982

[66] Jonas Löwgren. 2007. Fluency as an Experiential Quality in Augmented Spaces. *International Journal of Design* 1, 3 (Dec 2007), 1–10.

[67] Jonas Löwgren. 2007. Pliability As An Experiential Quality: Exploring The Aesthetics Of Interaction Design. *ARTIFACT* 1 (Oct 2007), 85–95. https://doi.org/10.1080/17493460600976165

[68] Jonas Löwgren. 2009. Toward an Articulation of Interaction Esthetics. *New Rev. Hypermedia Multimedia* 15, 2 (2009), 129–146. https://doi.org/10.1080/13614560903117822

[69] Tomosuke Maeda and Tetsuo Kurahashi. 2019. TherModule: Wearable and Modular Thermal Feedback System Based on a Wireless Platform. In *Proceedings of the 10th Augmented Human International Conference 2019* (Reims, France) *(AH2019)*. Association for Computing Machinery, New York, NY, USA, Article 14, 8 pages. https://doi.org/10.1145/3311823.3311826

[70] Angelo Maravita and Atsushi Iriki. 2004. Tools for the body (schema). *Trends in Cognitive Sciences* 8, 2 (Feb. 2004), 79–86. https://doi.org/10.1016/j.tics.2003.12.008

[71] Svetlana Mironcika, Joanne Pek, Jochem Franse, and Ya Shu. 2016. Whoosh Gloves: Interactive Tool to Form a Dialog Between Dancer and Choreographer. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. Association for Computing Machinery, New York, NY, USA, 729–732. https://doi.org/10.1145/2839462.2872958

[72] Joseph W. Newbold, Nadia Bianchi-Berthouze, Nicolas E. Gold, Ana Tajadura-Jiménez, and Amanda CdC Williams. 2016. Musically Informed Sonification for Chronic Pain Rehabilitation: Facilitating Progress & Avoiding Over-Doing. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, New York, NY, USA, 5698–5703. https://doi.org/10.1145/2858036.2858302

[73] Stina Nylander, Alex Kent, and Jakob Tholander. 2014. Swing Sound: Experiencing the Golf Swing Through Sound. In *CHI '14 Extended Abstracts on Human Factors in Computing Systems (CHI EA '14)*. ACM, New York, NY, USA, 443–446. https://doi.org/10.1145/2559206.2574789

[74] Pablo Palacio and Daniel Bisig. 2017. Piano&Dancer: Interaction Between a Dancer and an Acoustic Instrument. In *Proceedings of the 4th International Conference on Movement Computing (MOCO '17)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3077981.3078052

[75] Jeroen Peeters, Ambra Trotto, and Stoffel Kuenen. 2016. MoCap Tango: Traces of Complexity. In *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '16)*. Association for Computing Machinery, New York, NY, USA, 545–550. https://doi.org/10.1145/

2839462.2856544

[76] Edgar F Pierce and Myra L Daleng. 1998. Distortion of Body Image among Elite Female Dancers. *Perceptual and Motor Skills* 87, 3 (Dec. 1998), 769–770. https://doi.org/10.2466/pms.1998.87.3.769 Publisher: SAGE Publications Inc.

[77] Ivelina V. Piryankova, Jeanine K. Stefanucci, Javier Romero, Stephan De La Rosa, Michael J. Black, and Betty J. Mohler. 2014. Can I Recognize My Body's Weight? The Influence of Shape and Texture on the Perception of Self. *ACM Transactions on Applied Perception* 11, 3 (Sept. 2014), 13:1–13:18. https://doi.org/10.1145/2641568

[78] Ivelina V Piryankova, Hong Yu Wong, Sally A Linkenauger, Catherine Stinson, Matthew R Longo, Heinrich H Bülthoff, and Betty J Mohler. 2014. Owning an overweight or underweight body: distinguishing the physical, experienced and virtual body. *PloS one* 9, 8 (Aug. 2014), e103428–e103428. https://doi.org/10.1371/journal.pone.0103428 Publisher: Public Library of Science.

[79] Olga Pollatos, Anne-Lene Kurz, Jessica Albrecht, Tatjana Schreder, Anna Maria Kleemann, Veronika Schöpf, Rainer Kopietz, Martin Wiesmann, and Rainer Schandry. 2008. Reduced perception of bodily signals in anorexia nervosa. *Eating Behaviors* 9, 4 (Dec. 2008), 381–388. https://doi.org/10.1016/j.eatbeh.2008.02.001

[80] Jean-Philippe Rivière, Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy E. Mackay. 2018. How Do Dancers Learn To Dance?: A First-person Perspective of Dance Acquisition by Expert Contemporary Dancers. In *Proceedings of the 5th International Conference on Movement and Computing (MOCO '18)*. ACM, New York, NY, USA, 6:1–6:7. https://doi.org/10.1145/3212721.3212723 event-place: Genoa, Italy.

[81] Jean-Philippe Rivière, Sarah Fdili Alaoui, Baptiste Caramiaux, and Wendy E. Mackay. 2019. Capturing Movement Decomposition to Support Learning and Teaching in Contemporary Dance. *Proc. ACM Hum.-Comput. Interact.* 3, CSCW (Nov. 2019), 86:1–86:22. https://doi.org/10.1145/3359188

[82] Stephen Roddy and Dermot Furlong. 2014. Embodied aesthetics in auditory display. *Organised Sound* 19 (2014). Issue 1. https://doi.org/10.1017/S1355771813000423

[83] Rachel F. Rodgers, Elizabeth Donovan, Tara Cousineau, Kayla Yates, Kayla McGowan, Elizabeth Cook, Alice S. Lowy, and Debra L. Franko. 2018. BodiMojo: Efficacy of a Mobile-Based Intervention in Improving Body Image and Self-Compassion among Adolescents. *Journal of Youth and Adolescence* 47 (7 2018), 1363–1372. Issue 7. https://doi.org/10.1007/S10964-017-0804-3/TABLES/2

[84] Giulio Rosati, Antonio Rodà, Federico Avanzini, and Stefano Masiero. 2013. On the role of auditory feedback in robot-assisted movement training after stroke: review of the literature. *Computational Intelligence and Neuroscience* 2013 (2013), 586138. https://doi.org/10.1155/2013/586138

[85] Josef Roth, Jan Ehlers, Christopher Getschmann, and Florian Echtler. 2021. TempoWatch: a Wearable Music Control Interface for Dance Instructors. In *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '21)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3430524.3442461

[86] Nina Schaffert, Thenille Braun Janzen, Klaus Mattes, and Michael H. Thaut. 2019. A Review on the Relationship Between Sound and Movement in Sports and Rehabilitation. *Frontiers in Psychology* 10 (2019). https://www.frontiersin.org/articles/10.3389/fpsyg.2019.00244

[87] Nina Schaffert and Klaus Mattes. 2015. Interactive Sonification in Rowing: Acoustic Feedback for On-Water Training. *IEEE MultiMedia* 22, 1 (Jan. 2015), 58–67. https://doi.org/10.1109/MMUL.2015.9 Conference Name: IEEE MultiMedia.

[88] Thecla Schiphorst. 2011. Self-evidence: Applying Somatic Connoisseurship to Experience Design. In *CHI '11 Extended Abstracts on Human Factors in Computing Systems (CHI EA '11)*. ACM, New York, NY, USA, 145–160. https://doi.org/10.1145/1979742.1979640

[89] Daniel S. Scholz, Sönke Rhode, Michael Großbach, Jens Rollnik, and Eckart Altenmüller. 2015. Moving with music for stroke rehabilitation: a sonification feasibility study. *Annals of the New York Academy of Sciences* 1337 (March 2015), 69–76. https://doi.org/10.1111/nyas.12691

[90] Tim Schürmann, Betty Jo Mohler, Jan Peters, and Philipp Beckerle. 2019. How Cognitive Models of Human Body Experience Might Push Robotics. , 14 pages. https://www.frontiersin.org/article/10.3389/fnbot.2019.00014

[91] Ralf Schwarzer. 1992. Self-Efficacy, Physical Symptoms, and Rehabilitation of Chronic Disease. In *Self-Efficacy*, Ralf Schwarzer (Ed.). Taylor & Francis. Num Pages: 110.

[92] Jinsil Hwaryoung Seo, Michael Bruner, Nathan Ayres, Christine Bergeron, and Alexandra Pooley. 2019. Upwell: Performative Immersion Hybridizing Two Worlds. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. Association for Computing Machinery, New York, NY, USA, 571–575. https://doi.org/10.1145/3294109.3301264

[93] Andrea Serino and Patrick Haggard. 2010. Touch and the body. *Neuroscience & Biobehavioral Reviews* 34, 2 (feb 2010), 224–236. https://doi.org/10.1016/j.neubiorev.2009.04.004

[94] Matthias Seuter, Max Pfeiffer, Gernot Bauer, Karen Zentgraf, and Christian Kray. 2017. Running with Technology: Evaluating the Impact of Interacting with Wearable Devices on Running Movement. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1, 3 (Sept. 2017), 101:1–101:17. https://doi.org/10.1145/3130966

[95] Richard Shusterman. 2008. *Body Consciousness: A Philosophy of Mindfulness and Somaesthetics*. Cambridge University Press.

[96] Roland Sigrist, Georg Rauter, Laura Marchal-Crespo, Robert Riener, and Peter Wolf. 2015. Sonification and haptic feedback in addition to visual feedback enhances complex motor task learning. *Experimental Brain Research* 233, 3 (March 2015), 909–925. https://doi.org/10.1007/s00221-014-4167-7

[97] Roland Sigrist, Georg Rauter, Robert Riener, and Peter Wolf. 2013. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: A review. *Psychonomic Bulletin & Review* 20, 1 (Feb. 2013), 21–53. https://doi.org/10.3758/s13423-012-0333-8

[98] Aneesha Singh, Nadia Bianchi-Berthouze, and Amanda CdeC Williams. 2017. Supporting Everyday Function in Chronic Pain Using Wearable Technology. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 3903–3915. https://doi.org/10.1145/3025453.3025947

[99] Aneesha Singh, Stefano Piana, Davide Pollarolo, Gualtiero Volpe, Giovanna Varni, Ana Tajadura-Jiménez, Amanda CdeC Williams, Antonio Camurri, and Nadia Bianchi-Berthouze. 2016. Go-with-the-Flow: Tracking, Analysis and Sonification of Movement and Breathing to Build Confidence in Activity Despite Chronic Pain. *Human–Computer Interaction* 31, 3-4 (July 2016), 335–383. https://doi.org/10.1080/07370024.2015.1085310 Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/07370024.2015.1085310.

[100] Genevieve Smith-Nunes, Alex Shaw, and Camilla Neale. 2018. PainByte: Chronic Pain and BioMedical Engineering Through the Lens of Classical Ballet & Virtual Reality. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '18)*. Association for Computing Machinery, New York, NY, USA, 493–497. https://doi.org/10.1145/3173225.3173296

[101] Salvador Soto-Faraco, Daria Kvasova, Emmanuel Biau, Nara Ikumi, Manuela Ruzzoli, Luis Morís-Fernández, and Mireia Torralba. 2019. Multisensory Interactions in the Real World. https://doi.org/DOI:10.1017/9781108578738

[102] Daniel Spelmezan, Anke Hilgers, and Jan Borchers. 2009. A language of tactile motion instructions. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '09)*. Association for Computing Machinery, New York, NY, USA, 1–5. https://doi.org/10.1145/1613858.1613896

[103] Tasha R. Stanton, G. Lorimer Moseley, Arnold Y. L. Wong, and Gregory N. Kawchuk. 2017. Feeling stiffness in the back: a protective perceptual inference in chronic back pain. *Scientific Reports* 7, 1 (Aug. 2017), 9681. https://doi.org/10.1038/s41598-017-09429-1 Number: 1 Publisher: Nature Publishing Group.

[104] Jelle Stienstra, Kees Overbeeke, and Stephan Wensveen. 2011. Embodying Complexity through Movement Sonification: Case Study on Empowering the Speed-Skater. In *Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity* (Alghero, Italy) *(CHItaly)*. Association for Computing Machinery, New York, NY, USA, 39–44. https://doi.org/10.1145/2037296.2037310

[105] Jelle Stienstra, Kees Overbeeke, and Stephan Wensveen. 2011. Embodying Complexity Through Movement Sonification: Case Study on Empowering the Speed-skater. In *Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity (CHItaly)*. ACM, New York, NY, USA, 39–44. https://doi.org/10.1145/2037296.2037310 event-place: Alghero, Italy.

[106] Anna Ståhl, Madeline Balaam, Rob Comber, Pedro Sanches, and Kristina Höök. 2022. Making New Worlds – Transformative Becomings with Soma Design. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–17. https://doi.org/10.1145/3491102.3502018

[107] Ana Tajadura-Jimenez, Judith Ley-Flores, Omar Valdiviezo, Aneesha Singh, Milagrosa Sanchez-Martin, Joaquin Diaz Duran, and Elena Márquez Segura. 2022. Exploring the Design Space for Body Transformation Wearables to Support Physical Activity through Sensitizing and Bodystorming. In *Proceedings of the 8th International Conference on Movement and Computing (MOCO '22)*. Association for Computing Machinery, New York, NY, USA. https://doi.org/10.1145/3537972.3538001

[108] Ana Tajadura-Jiménez, D. Banakou, N. Bianchi-Berthouze, and M. Slater. 2017. Embodiment in a Child-Like Talking Virtual Body Influences Object Size Perception, Self-Identification, and Subsequent Real Speaking. *Scientific Reports* 7, 1 (2017). https://doi.org/10.1038/s41598-017-09497-3

[109] Ana Tajadura-Jiménez, Maria Basia, Ophelia Deroy, Merle Fairhurst, Nicolai Marquardt, and Nadia Bianchi-Berthouze. 2015. As Light as your Footsteps: Altering Walking Sounds to Change Perceived Body Weight, Emotional State and Gait. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2943–2952. https://doi.org/10.1145/2702123.2702374

[110] Ana. Tajadura-Jiménez, N. Bianchi-Berthouze, E. Furfaro, and F. Bevilacqua. 2015. Sonification of surface tapping changes behavior, surface perception, and emotion. *IEEE Multimedia* 22, 1 (2015). https://doi.org/10.1109/MMUL.2015.14

[111] Ana Tajadura-Jiménez, Merle T. Fairhurst, and Ophelia Deroy. 2022. Sensing the body through sound. *The Routledge Handbook of Bodily Awareness* (11 2022), 230–246. https://doi.org/10.4324/9780429321542-21

[112] Ana Tajadura-Jiménez, S. Grehl, and M. Tsakiris. 2012. The other in me: Interpersonal multisensory stimulation changes the mental representation of the self. *PLoS ONE* 7, 7 (2012). https://doi.org/10.1371/journal.pone.0040682

[113] Ana Tajadura-Jiménez, Torsten Marquardt, David Swapp, Norimichi Kitagawa, and Nadia Bianchi-Berthouze. 2016. Action Sounds Modulate Arm Reaching Movements. *Frontiers in Psychology* 7 (2016), 1391. http://journal.frontiersin.org/article/10.3389/fpsyg.2016.01391 ISBN: 1664-1078.

[114] Ana Tajadura-Jiménez, Joseph Newbold, Linge Zhang, Patricia Rick, and Nadia Bianchi-Berthouze. 2019. As Light as You Aspire to Be. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM, New York, NY, USA, 1–14. https://doi.org/10.1145/3290605.3300888

[115] Ana Tajadura-Jiménez, Manos Tsakiris, Torsten Marquardt, and Bianchi Berthouze Nadia. 2015. Action sounds update the mental representation of arm dimension: Contributions of kinaesthesia and agency. *Frontiers in Psychology* 6, May (2015), 1–18. https://doi.org/10.3389/fpsyg.2015.00689

[116] Ana Tajadura-Jiménez, Aleksander Valjamae, and Kristi Kuusk. 2020. Altering One's Body-perception Through E-Textiles and Haptic Metaphors. *Frontiers in Robotics and AI* (2020). https://doi.org/10.3389/frobt.2020.00007

[117] Ana Tajadura-Jiménez, Aleksander Väljamäe, Iwaki Toshima, Toshitaka Kimura, Manos Tsakiris, and Norimichi Kitagawa. 2012. Action sounds recalibrate perceived tactile distance. *Current Biology* 22, 13 (2012), R516–R517. https://doi.org/10.1016/j.cub.2012.04.028 ISBN: 1879-0445 (Electronic)\r0960-9822 (Linking) Publisher: Elsevier.

[118] Paul Tennent, Joe Marshall, Vasiliki Tsaknaki, Charles Windlin, Kristina Höök, and Miquel Alfaras. 2020. Soma Design and Sensory Misalignment. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376812

[119] J Kevin Thompson and Eric Stice. 2001. Thin-Ideal Internalization: Mounting Evidence for a New Risk Factor for Body-Image Disturbance and Eating Pathology. *Current Directions in Psychological Science* 10, 5 (Oct. 2001), 181–183. https://doi.org/10.1111/1467-8721.00144 Publisher: SAGE Publications Inc.

[120] Milka Trajkova and Francesco Cafaro. 2018. Takes Tutu to Ballet: Designing Visual and Verbal Feedback for Augmented Mirrors. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 2, 1 (March 2018), 38:1–38:30. https://doi.org/10.1145/3191770

[121] Milka Trajkova, Francesco Cafaro, and Lynn Dombrowski. 2019. Designing for Ballet Classes: Identifying and Mitigating Communication Challenges Between Dancers and Teachers. In *Proceedings of the 2019 on Designing Interactive Systems Conference (DIS '19)*. ACM, New York, NY, USA, 265–277. https://doi.org/10.1145/3322276.3322312 event-place: San Diego, CA, USA.

[122] Manos Tsakiris † and Patrick Haggard. 2005. Experimenting with the acting self. *Cognitive Neuropsychology* 22, 3-4 (May 2005), 387–407. https://doi.org/10.1080/02643290442000158 Publisher: Routledge _eprint: https://doi.org/10.1080/02643290442000158.

[123] Vasiliki Tsaknaki. 2021. The Breathing Wings: An Autobiographical Soma Design Exploration of Touch Qualities through Shape-Change Materials. In *Designing Interactive Systems Conference 2021 (DIS '21)*. Association for Computing Machinery, New York, NY, USA, 1266–1279. https://doi.org/10.1145/3461778.3462054

[124] Laia Turmo Vidal, Yinchu Li, Martin Stojanov, Karin B Johansson, Beatrice Tylstedt, and Lina Eklund. 2023. Towards Advancing Body Maps as Research Tool in Interaction Design. (2023), 470–475.

[125] Laia Turmo Vidal, Elena Márquez Segura, Luis Parrilla Bel, and Annika Waern. 2020. Training Technology Probes Across Fitness Practices: Yoga, Circus and Weightlifting. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems (CHI'20)*. ACM, New York, NY, USA. https://doi.org/10.1145/3334480.3382862

[126] Laia Turmo Vidal, Elena Márquez Segura, and Annika Waern. 2023. Intercorporeal Biofeedback for Movement Learning. *ACM Transactions on Computer-Human Interaction* 30, 3 (June 2023), 43:1–43:40. https://doi.org/10.1145/3582428

[127] Laia Turmo Vidal, Hui Zhu, and Abraham Riego-Delgado. 2020. BodyLights: Open-Ended Augmented Feedback to Support Training Towards a Correct Exercise Execution. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376268

[128] Laia Turmo Vidal, Hui Zhu, Annika Waern, and Elena Márquez Segura. 2021. The Design Space of Wearables for Sports and Fitness Practices. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama Japan, 1–14. https://doi.org/10.1145/3411764.3445700

[129] Björn van der Hoort, Arvid Guterstam, and H Henrik Ehrsson. 2011. Being Barbie: The Size of One's Own Body Determines the Perceived Size of the World. *PLOS ONE* 6, 5 (May 2011), e20195. https://doi.org/10.1371/journal.pone.0020195 Publisher: Public Library of Science.

[130] Elizabeth Walton and Wendy E. Mackay. 2022. Dance Transitions: What Forms of Technology Best Support Professional Dancers as They Learn New Movement Styles?. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3491102.3517448

[131] Daniel M. Wolpert and Zoubin Ghahramani. 2000. Computational principles of movement neuroscience. *Nature Neuroscience* 3, 11 (Nov. 2000), 1212–1217. https://doi.org/10.1038/81497 Number: 11 Publisher: Nature Publishing Group.

[132] Mikoklaj P. Wozniak, Julia Dominiak, Michal Pieprzowski, Piotr ladonski, Krzysztof Grudzien, Lars Lischke, Andrzej Romanowski, and Pawel W. Wozniak. 2020. Subtletee: Augmenting Posture Awareness for Beginner Golfers. *Proc. ACM Hum.-Comput. Interact.* 4, ISS, Article 204 (nov 2020), 24 pages. https://doi.org/10.1145/3427332

[133] Qiushi Zhou, Cheng Cheng Chua, Jarrod Knibbe, Jorge Goncalves, and Eduardo Velloso. 2021. Dance and Choreography in HCI: A Two-Decade Retrospective. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3411764.3445804

[134] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704