Exploring Material Metaphors to Design Sensorial Wearables for Body Transformation Experiences

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Our work combines neuroscience and HCI to design Body Transformation Experiences, where altering bodily sensory feedback gives rise to perceptual illusions of one's body changing, leading also to motor, social, and emotional changes. This paper focuses on strategies, methods and prototypes for designing these experiences, including the use of material metaphors to transform body perceptions. We contribute a wearable device, called SoniBand, which sonifies body movement using material metaphors with the aim to link sounds (e.g. water) to body perceptions (e.g. being fluid and moving faster). We also contribute a method, Sensory Bodystorming, to open the design space of material-enabled body-based multisensory experiences. We also share insights from studies using SoniBand with physically inactive individuals and professional dancers, in terms of effects on body perceptions, movement, and emotion. We seek to explore the potential of materials to enable transformations and support people's health and behavior change.

Additional Key Words and Phrases: body transformation experiences, sensory feedback, material metaphors, movement sonification, haptic feedback, body perception, wearables

ACM Reference Format:

Laia Turmo Vidal, Judith Ley-Flores, Elena Márquez Segura, and Ana Tajadura-Jiménez. 2023. Exploring Material Metaphors to Design Sensorial Wearables for Body Transformation Experiences. In . ACM, New York, NY, USA, 4 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION

Neuroscientific and HCI research has shown that body perceptions are not fixed, but are continuously updated through sensory and motor signals [1, 6]. In our group, we build on this and work towards creating Body Transformation Experiences; these are those in which altering bodily sensory feedback gives rise to perceptual illusions of one's body changing, such as having longer arms [19], a smaller or bigger body [8, 12] or enhanced body capabilities [3, 4]. The impact of such Body Transformation Experiences can lead to changes in motor [13, 16] and social behavior [7], emotions [3, 13], body satisfaction [8], and self-identity [17], opening application possibilities for sports, health, embodiment of avatars and robotic devices [2, 9, 14], apart from entertainment and new art forms.

We investigate how sound, haptic and movement signals can be used to induce illusions of one's body changing. In this position paper, we present strategies, methods, and prototypes to design for Body Transformation Experiences.

2 STRATEGY: USING MATERIAL METAPHORS

We constantly produce sounds as our bodies touch objects and surfaces, e.g. when we touch a table, drop a ball or walk on a wooden floor. These sounds can significantly influence our perception of materiality [11], and also the perceptions

Manuscript submitted to ACM

Fig. 1. **SoniBand**'s technical elements and an example of wear with an angular movement sequence that would activate it.

of our body[19]. Our studies showed that modifying the sound feedback during touch interactions can lead to changes in the perceived body size. For example, hearing the sounds produced by tapping a surface from a greater distance can create the illusion of a longer arm and impact subsequent arm movements [16, 19]. We also found that altering the frequency spectra of the sounds produced when walking on a surface can create the illusion of a lighter body, and in turn affect gait and emotional state [13].

In our recent works we have started to look at the potential of designing sound and haptic stimulation using "material metaphors" to tackle and transform different body perceptions by employing, not only *bottom-up mechanisms*, based on the spatiotemporal correlation of sensory signals; but also *top-down mechanisms*, involving memories and previous experiences that shape perception [15]. Our exploratory studies on haptic "material metaphors" showed potential in linking materials (e.g., rocks) to body perceptions (e.g., being heavy, strong) to trigger changes in body perception and emotion [18]. In our works, we have also been exploring the potential of sonifying body movements to change people's feelings about their body and their movements [3], and in particular, the use of sonic "material metaphors" with the aim of linking sounds (e.g. water) to body perceptions (e.g. being fluid and moving faster) [4, 5, 11].

3 PROTOTYPE: SONIBAND, A WEARABLE DEVICE THAT SONIFIES BODY MOVEMENT WITH MATERIAL METAPHORS

In our work, we have employed neuroscientific knowledge on body and sensory perception and designed and used prototypes to support body transformation experiences of particular populations.

We will present the SoniBand, a wearable device that provides real-time sonification of movement through a variety of movement-generated sounds. The device is embedded in a silicon bracelet and can be worn on different body parts, e.g. arm, leg, neck, see Figure 1. It incorporates a BITalino R-IoT with an Inertial Motion Unit. The movement data is wirelessly transmitted to a Raspberry Pi Zero that can be controlled through a web browser on a smartphone. SoniBand includes different sound conditions, some of which build on material metaphors. For example, "water", a sound of continuous running water throughout the movement, with an added "splash" sound of hitting water near the end position of the calibrated movement; or the discrete "mechanical" sound, that emulates rusty gears, and that plays throughout the movement and changes its frequency gradually as it gets near the calibrated end position [5].

SoniBand has been used in studies with people who are physically inactive [4, 5]. These people experience psychological and emotional barriers related to their body perceptions (such as tiredness, not feeling able or agile) that prevent adherence to physical activity. We found specific sound-movement combinations that impact feelings about the body

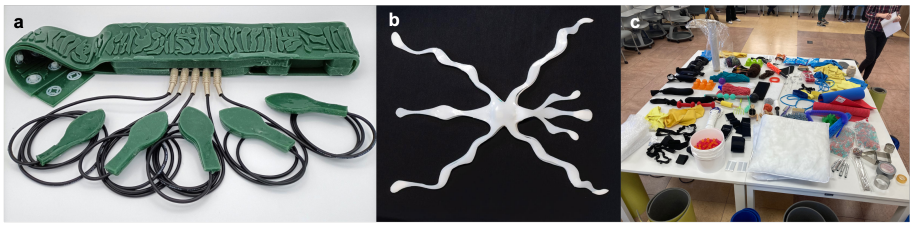

Fig. 2. (a) Vibrant wearable version, (b) vibrant object version, (c) sensory probes with diverse material properties used for ideation.

(e.g., feeling stronger), the movement (e.g. faster movements) and emotion (e.g., comfort, happiness), and which also affect movement behavior (e.g., increasing acceleration) and proprioceptive awareness [3–5].

4 METHOD: SENSORY BODYSTORMING AND PROTOTYPES AS DESIGN MATERIAL TO OPEN THE DESIGN SPACE OF MATERIAL-ENABLED BODY-BASED MULTISENSORY EXPERIENCES

We will also bring to the workshop a demonstration of the embodied design-based methods that we employ to open up the design space of material-enabled body-based multisensory experiences [10].

Sensory Bodystorming. We will demonstrate our use of Sensory Bodystorming [20] as method to sensitise participants (often without technical expertise) and to generate ideas for designing rich sensory experiences. The method involves physically engaging with various sensorial stimuli, prompted by sensory probes with diverse material properties - such as different shapes, weights, and textures (e.g., soft/hard/rough/elastic) selected to produce qualitatively different sensorial stimuli. Such probes are often craft-material (e.g., bubble wrap, carton, rubber bands), or off-the-shelf objects, (e.g., sponges, scratchers, marbles). By engaging in specific situations and aspects relevant to the target design activity, participants can explore the potential of different sensory stimuli and imagine future prototypes. Often, facilitation is necessary to help participants fully leverage the performative nature of the probes, and to translate generated ideas into concrete design concepts.

In our group, we have employed Sensory Bodystorming in several projects. One example is in explorations with people on how sensory feedback could help activate them physically [10]. Through the use of Sensory Bodystorming, participants explored what sensory inputs would work best for them to get physically activated, ultimately resulting in the design of Vibrants, two haptic actuation devices (a wearable version, see Figure 2, and an object version, see Figure 2) that provide vibrotactile feedback to facilitate movement. The wearable version provides linear feedback on body movement (angle changes) that activates bottom-to-top or top-to-down sequences respectively during upward and downward movements. The object version is made of silicon and has a simpler array of vibrating mini-motor discs, controlled through an app. The vibrotactile feedback can be configured in various patterns, speeds, and frequencies.

Prototypes as Design Material for Body Transformation Experiences. Recently, we have also explored the use of SoniBand with professional dancers who experience negative body perceptions. SoniBand affected how individuals perceived their body size, weight, capabilities, and overall body awareness. Furthermore, it influenced the speed, fluidity, weight, and endurance of movement, also promoting specific types of movements. The use of SoniBand was associated with positive emotional experiences, such as pleasure, joy, feelings of freedom, amusement, curiosity, and empowerment.

To the workshop, we will bring a selection of sensory probes and Soniband and facilitate a short mock-up ideation session, so participants get sensitised to the potential of the probes to elicit thinking about, feeling and ideating different sensory inputs.

5 ACKNOWLEDGMENTS

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 101002711) and the Agencia Estatal de Investigación (MCIN/AEI/10.13039/501100011033/).

REFERENCES

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

[2] Alba Gomez-Andres, Jennifer Grau-Sánchez, Esther Duarte, Antoni Rodriguez-Fornells, and Ana Tajadura-Jiménez. 2020. Enriching footsteps sounds in gait rehabilitation in chronic stroke patients: a pilot study. *Annals New York Academy Sciences* 1467 (2020), 48–59. https://doi.org/10.1111/nyas.14276

[3] 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

[4] 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.*

[5] 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

[6] 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

[7] Lara Maister, Mel Slater, Maria V. Sanchez-Vives, and Manos Tsakiris. 2015. Changing bodies changes minds: Owning another body affects social cognition. Issue 1. https://doi.org/10.1016/j.tics.2014.11.001

[8] Catherine Preston and H Henrik Ehrsson. 2014. Illusory Changes in Body Size Modulate Body Satisfaction in a Way That Is Related to Non-Clinical Eating Disorder Psychopathology. *PLOS ONE* 9, 1 (jan 2014), e85773. https://doi.org/10.1371/journal.pone.0085773

[9] Maria V. Sanchez-Vives and Mel Slater. 2005. From presence to consciousness through virtual reality. *Nature Reviews Neuroscience 2005 6:4* 6 (2005), 332–339. Issue 4. https://doi.org/10.1038/nrn1651

[10] 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).* ACM, USA. https://doi.org/10.1145/3537972.3538001

[11] Ana Tajadura-Jimenez, Bin Liu, Nadia Bianchi-Berthouze, and Frédéric Bevilacqua. 2014. Using Sound in Multi-Touch Interfaces to Change Materiality and Touch Behavior. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational* (Helsinki, Finland) *(NordiCHI '14).* Association for Computing Machinery, New York, NY, USA, 199–202. https://doi.org/10.1145/2639189.2639217

[12] 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

[13] 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

[14] Ana Tajadura-Jiménez, Laura Crucianelli, Rebecca Zheng, Chloe Cheng, Judith Ley-Flores, Mercedes Borda-Más, Nadia Bianchi-Berthouze, and Aikaterini Fotopoulou. 2022. Body weight distortions in an auditory-driven body illusion in subclinical and clinical eating disorders. *Scientific Reports 2022 12:1* 12 (11 2022), 1–17. Issue 1. https://doi.org/10.1038/s41598-022-24452-7

[15] 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

[16] 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.

[17] Ana Tajadura-Jiménez and M. Tsakiris. 2014. Balancing the "inner" and the "outer" self: Interoceptive sensitivity modulates self-other boundaries. *Journal of Experimental Psychology: General* 143, 2 (2014). https://doi.org/10.1037/a0033171

[18] 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

[19] 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

[20] Laia Turmo Vidal, Elena Márquez Segura, and Annika Waern. 2018. Sensory bodystorming for collocated physical training design. In *Proceedings of the 10th Nordic Conference on Human-Computer Interaction (NordiCHI '18).* Association for Computing Machinery, New York, NY, USA, 247–259. https://doi.org/10.1145/3240167.3240224