Exploring the Design Space for Body Transformation Wearables to Support Physical Activity through Sensitizing and Bodystorming

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Negative or disturbed body perceptions are often interwoven with people's physical inactivity. While wearables can support body perception changes (body transformation), the design space of body transformation wearables supporting physical activity remains narrow. To expand this design space, we conducted an embodied co-design workshop with users. Using conceptual and tangible sensitizing tools, we explored/reflected on bodily sensations at three moments of movement execution (before/during/after). Conceptual tools were used to evoke/reflect/capture past lived experiences, while tangible tools were used as ideation probes for sensory bodystorming. Two design concepts emerged, reflecting diverging approaches to body transformation wearables: one focused on reminders and movement correction; the other on sensory augmentation and facilitation. We reflect on how each facilitates useful representations of body sensations during movement, and present methodological recommendations for designing technology for sensory augmentation in this area. Finally, we propose a preliminary prototype based on our design concepts and discuss future steps.

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CCS CONCEPTS •Human-centered computing~Human computer interaction (HCI)•Human-centered computing~Human computer interaction (HCI)~Interaction techniques~Gestural input•Human-centered computing~Interaction design~Interaction design process and methods•Human-centered computing~Interaction design~Systems and tools for interaction design•Applied computing~Arts and humanities~Sound and music computing•Applied computing~Law, social and behavioral sciences~Psychology

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1 Introduction

Physical inactivity is a serious worldwide problem [47] and has been the focus of technology design in general, and wearables in particular for a long while. Current mainstream wearable design approaches have focused on activity tracking (e.g., Fitbit, GoogleFit) and employing personal informatics [16,31] to support behavior change [14], e.g. providing feedback on the amount of physical activity (PA) performed and setting goals to increase motivation for PA [17]. However, for many, and specially for those struggling to engage in PA, this approach is often insufficient. An alternative complementary approach [16] involves tapping into other psychological factors beyond motivation, such as negative body-perceptions (e.g., lack of self-efficacy, weight stigma) and associated emotional feelings, which are linked to, and can drive people to low PA [27,30,34,35,45]. With this aim, a recent research line investigates the potential of using auditory feedback to alter body-perceptions, and in turn emotional state, in the context of facilitating PA [12,19-21,36,40]. The key to these "Body Transformation Experiences" is the alteration of immediate bodily sensory feedback received from action/movement, which builds on neuroscience principles on body-perception [2,23] and motor-to-sensory transformations [48]. However, the understanding of those mechanisms and the principles to design sensorial technologies to support those experiences and PA are still evolving. This study explores the question of how to design sensory feedback and technologies to hack sensorimotor loops and support changes in body-perceptions and in turn PA.

Movement sonification, mapping body movement into real-time auditory feedback, is often used in PA contexts, including sports and physical rehabilitation, for movement guidance and correction, and to improve motor performance [1,33]. Sound can also provide information that may not be available otherwise, e.g. in populations with chronic pain and low proprioception, and help address psychological barriers to PA (e.g., worry about pain/injury during movement) [35]. Alternatively, sound feedback can be specially designed to change body-perceptions. Recent works have shown that the alteration of the naturally occurring bodily sounds (e.g., footstep sounds [12,36,38-41]) and the metaphorical sonification of movement (e.g., water sounds paired with body movement [19-21]) can potentially alter body-perceptions, emotional states, and PA. However, designing such sonifications can be very challenging and much work still needs to be done on how to best map auditory and sensory cues to specific body-perceptions, body sensations (BodyS) and movements to facilitate PA.

Here we present the methods and outcomes of a first embodied ideation workshop, part of MagicOutFit (https://magicoutfit.com), a research project investigating how to support people to engage in PA through sensory-driven changes in body-perception. In the project, a set of wearable sound technologies had already been designed to target different body-perceptions based on users' needs as identified in the literature, and have been evaluated with users. With this workshop, we aimed to:

- test the potential of a series of tools and methods to better understand users' body-perceptions at different moments of engagement in PA (before/during/after) and to open the design space of body transformation wearables to support PA, such as bodystorming with physical/technology ideation probes, or sensitizing participants and designers with contextual bodymaps and keywords featuring BodyS and emotions;
- expand the design space of body transformation wearables to support PA through co-creating ideas for wearable designs with end-users; and
- iterate technological prototypes from previous works on sound-induced body transformation experiences

Our work presents three main contributions:

- Two design concepts that map haptic cues to specific movements and body-perceptions, which differ in their approach to PA (i.e., correcting vs sensory facilitation of exercise);
- A novel technological prototype inspired by the developed design concepts;
- Novel contextual bodymaps to capture BodyS at three different moments of movement execution, complemented by keywords on BodyS and emotions; insights on the potential value of using these for sensitizing in body-based design research [10,21,22,42].

2 Methods

Towards opening the design space of wearable sensory technologies for supporting PA focusing on body perceptions we engaged in an embodied ideation workshop featuring sensitizing, bodystorming, and co-design activities [24-26,43].

2.1 Participants and facilitators

We gathered ten participants (18-42 years old; six men, four women), with varied backgrounds and design skills (see Table 1). The research was approved by the local ethics committee at Universidad Carlos III de Madrid. An informed consent was obtained from the volunteers.

Table 1: Description of workshop participants (number and experience), including volunteer end-users, and the design/research team, which was involved in all the workshop activities to facilitate body engagement, exploration and ideation.

Participants	Experience/Role
6 volunteers, naïve to research aims	4 participants without HCI or ideation methods experience 2 HCI researchers with no experience in embodied ideation methods
4 workshop organizers/facilitators	1 main facilitator (last author): an HCI researcher experienced in embodied ideation methods and physical training, who guided the participants in body sensitizing and ideation activities 3 HCI researchers with a design background and experience in body-centred sensory technologies who co-facilitated and helped document the session.

2.2 Workshop structure

The workshop lasted two hours. Table 2 summarizes the structure of the workshop and the different techniques employed.

Table 2: Workshop structure and techniques employed

Technique/aim	Description
Introduction	Participant introduction. Introduction to the project.
Warming up	Physical warm-up, exploration of movement qualities, bodies and space.
Body sensitizing through movement	Guided activity experiencing three basic everyday physical activities: walking (in particular, taking a first step); and standing up from sitting down, and lying down. Focus on defamiliarization: engaging with these activities in different ways, with different BodyS focus, and goals, intentionality and priming certain body states and sensations.
Body sensitizing through keywords (bodyS, emotions)	Participants select 1 physical activity and reflect on BodyS and emotions before/during/after the exercise using two sets of selected keywords (see Supplementary Table): The BodyS set included 40 keywords (based on [15,21,40]) and the emotions set included 35 keywords based on [3-5,7,8,15,29,32]. Participants could also add additional keywords.
Body sensitizing through body maps	Drawing one's BodyS and emotions at those three moments using the keywords and a variation of bodymaps [22,42] (see Figure 1) to capture the link between BodyS, emotions, and body parts [28].
Short break	
Introducing sensory probes as sensitizing tools	Introduction of various sensory probes as sensitizing tools [24-26,43] to test and explain ideas. First, the technological probes developed in the project. Participants explored them (see Figure 2). Then, non-technological physical objects, ranging from simple household items like sponges, brushes, to crafting materials, weights or massage objects (see Figure 1). During the workshop, participants had access to all probes to experiment.
Sensorial exploration of the probes as catalyzers for ideation	Division of participants into two groups. Sensorial exploration of the probes. Bodystorming [24]: ideation through enactment, proposing ideas for prototypes that elicit/evoke sensations that make them move. Each idea was bodily explored, tested and iterated.
Sensorial enactment for ideation	Idea selection and enactment to the whole group. Group discussion about how to improve the design.
General discussion	General discussion on the session, methods, and designs.

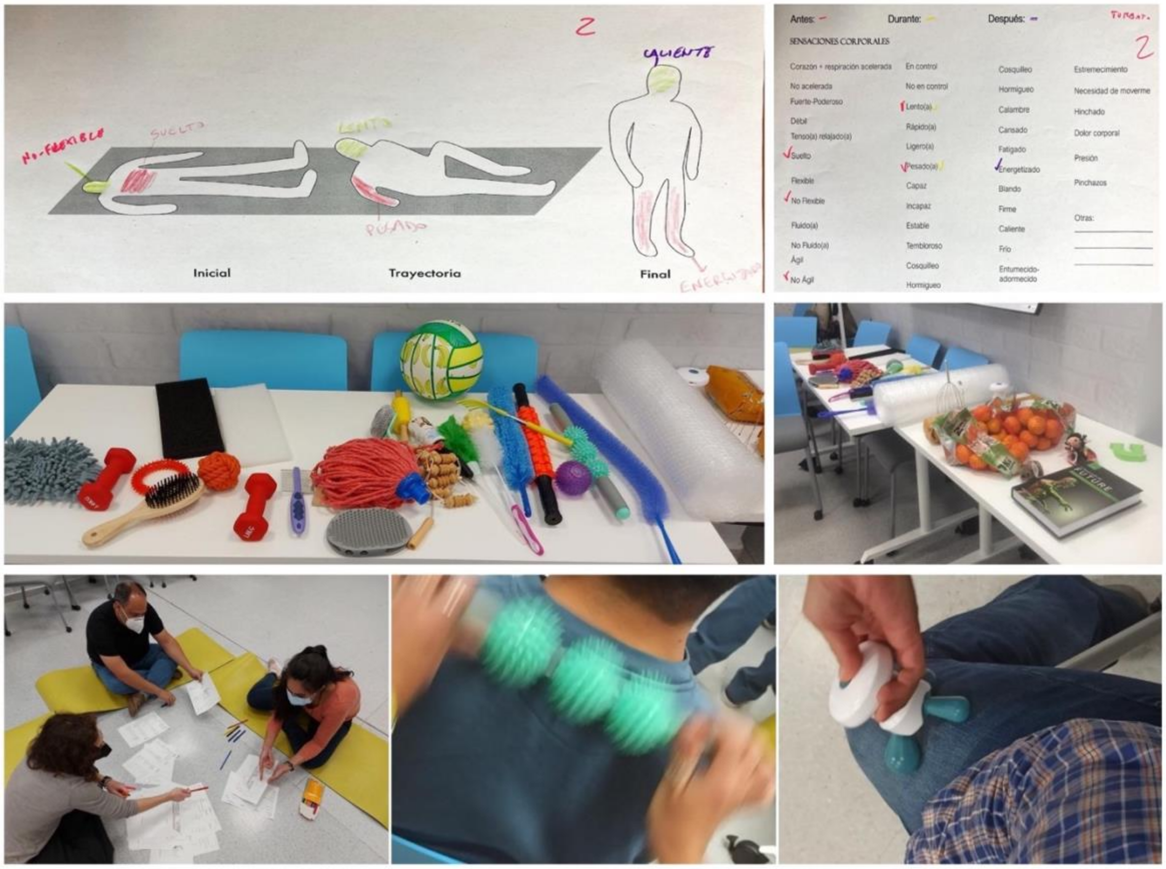

Figure 1: **Snippets from moments of the workshop. Top: Body sensitizing tools – Contextual Dynamic BodyMaps and Keywords on Body Sensations and Emotional feelings. Our bodymaps extend those in previous works, which typically consist of a single body silhouette [21], frequently seen from front and back, complemented with keywords (e.g., BodyS, emotions). Inspired by the bodymaps in [21], which feature two moments of movement execution, ours capture the BodyS during three moments: before/during/after movement execution for the three activities at focus: (1) laydown-to-stand; (2) sit-to-stand; (3) walking. This allowed participants linking the keywords to specific body parts as well as to provide more detail with their drawings on how these sensations/emotions are experienced. Top left: filled bodymap depicting BodyS for the laydown-to-stand exercise, depicting the sensations before ("Inicial"), during ("Trayectoria"), and at the end ("Final") of the exercise. Top right: filled "Body Sensations" keyword sheet highlighting in red sensations before ("antes"); in yellow during ("durante"); and in violet after ("después"). Middle: Ideation materials with different shapes, weights, textures (e.g., soft/hard/rough/elastic) selected to produce qualitatively different sensorial stimuli. We also brought a series of daily life items that participants could use to simulate everyday activities involving PA (e.g., mandarin bags, books, toys, volleyball, shopping trolley). The facilitator presented these other sensory (physical) probes and gave examples of everyday activities involving PA (e.g,. stretching to take a book from the bookshelf, carrying a heavy bag, etc). Bottom left: participants sharing their bodymaps. Bottom center/right: participants delivering tactile stimulation to others to elicit certain sensations during ideation.**

Figure 2: Technological Probes brought to the workshop. Top left: Soniband is a wearable band that integrates a BITalino R-IoT embedding a 9-axis Inertial Motion Unit (IMU). The R-IoT transmits movement angle data wirelessly to a Raspberry Pi Zero, which can be controlled using a web browser in e.g., a smartphone. The device registers the minimum and maximum angle of the body part (calibration), and then it sonifies movement angle real-time with five movement-sounds: "Wind", "Water", "Mechanical", "Ascending Tone" and "Beep." (see more details in [21]). In the workshop, the participants could choose the movement to sonify and the sound. Further details can be found in [21]. Top right: Example of movement sonified by Soniband. Bottom left: Sonishoes integrate a Soniband worn in the ankle and a sole that detects pressure against the ground and "sonifies" steps. Sonishoes allowed five different movement-sound conditions: "Aluminum can crush" (replicating the sense of pressing a coke can against the ground), "Wind" (a pink noise sound changing frequency which plays during the foot swing of a stride or in response to changes in leg angle), "Water" (a continuous sound of water running with a "splash" sound at certain angle), "Mechanical" (a gears sound changing with angle), and "Tone" (a continuous tone plays from start to end of the movement). Further details can be found in [20]. Bottom right: Sonicarpet is a simpler version of Sonishoes, which just sonifies steps when stepping on it (i.e., when detecting pressure against the ground).

3 RESULTS

Participants chose different exercises (3 sit-to-stand, 2 laydown-to-stand, 1 walking). They filled in the keywords sheets and the body maps, which yielded qualitatively different BodyS and emotions in each movement phase (before/during/after), as summarized in Table 3.

Table 3: **Summary of selected BodyS and emotions keywords, and associated body parts.**

Moment / Body parts	Summary of selected keywords (BodyS, emotions) and body parts
Before	Overall, the "before" BodyS related to inactivity (e.g., weak, inflexible, loose, not agile, not fluid, paralyzed), and feelings of calmness.
During	The "during" BodyS changed to energy/activation (e.g., powerful, energized, flexible, fluid, warm, tingling, heart/breath racing) and to positive feelings (e.g., cheerful, capable, confident, energized, daring, eager); some participants felt curious and surprised. Interestingly enough, the transition from negative to positive sensations mapped to inactivity and activation respectively was not observed in one participant, who chose the walking exercise, and who "before" already felt energized (needing/eager to move and accelerated). We reasoned that the significant change in posture from the rest (3 sit-to-stand; 2 laydown-to-stand) might be behind this notable transition. More work is needed to clarify this.
After	The "after" BodyS and emotions varied. Some reported energy/activation sensations (e.g., energized, excited, animated), as if prolonging the "during" phase; others' reported relief and relaxation sensations (e.g., steady, slow heart/breath). While some felt tired or exhausted, these sensations were linked to positive feelings (e.g., loose, relaxed, relieved, comfortable).
All moments	Other sensations reported in all movement phases are: feeling of pressure, tension or even muscle cramps, throbbing or prickling.
Selected body parts and associated sensations	Two body parts appeared more frequently in the bodymaps: the chest and thighs/legs, annotated with evolving sensations through the different phases, e.g. from weak and slow (before), to warm and energized (during), and then tired, relaxed and relieved (after). Hence, we reason these parts may have potential as hot spots for wearable devices. Other parts mentioned were head, knees, feet, abdomen, arms, hips, neck.

In the ideation phase, participants used the objects to create various PA scenarios (e.g. lifting weights, moving to collect an everyday object). Drawing on their material properties and physicalities, they explored various sensory feedbacks, which led to various design ideas and variations. Two of them were selected, polished, and presented to the whole group (see designs, key aspects and PA potential in Figures 3 and 4). While both design concepts featured vibrations delivered to the back, they reflect two diverging approaches for wearables to support body transformation and PA: one focused on correction of physical performance; and one focused on sensory augmentation and facilitation. Each focused on a particular kind of PA: pure exertion (weightlifting) vs functional PA (i.e., movement necessary to everyday activity, such as picking an object from the ground) respectively.

Figure 3: **Design Idea 1 - A waist band correcting posture through vibrations on the lower back. The device consists of an elastic band around the waist (left) that would be used to monitor weightlifting exercises (right) and signal incorrect back posture through vibration, which would trigger immediate posture correction.**

Figure 4: **Design Idea 2 - Pulling up and down through traveling vibration. The device would accompany the movement of the wearer with vibrations moving in the direction of the movement. In the sequence above, participants explored squatting with the device to pick up an object on the floor. While moving down, the vibration would travel from top to bottom along the spine, and vice versa. The participants described how this device enhanced their inner drive to move and facilitated their movement. They felt as if it was "pulling" them up or "pushing" them down.**

Last, we conclude with a preliminary prototype built after the workshop to materialize both design concepts for further evaluation. This prototype delivers vibratory patterns through vibrating minimotor discs placed along the spine and extending laterally from the spine towards the shoulders, waist, and lower back areas (see Figure 5). Inspired in Design Idea 2, these vibrators activate sequentially, from bottom to top, during an upwards movement, or reversely during a downwards movement. Vibrations could be also delivered just to the lower back like in Design Idea 1. Future steps involve testing this prototype with users in the two scenarios proposed by our participants.

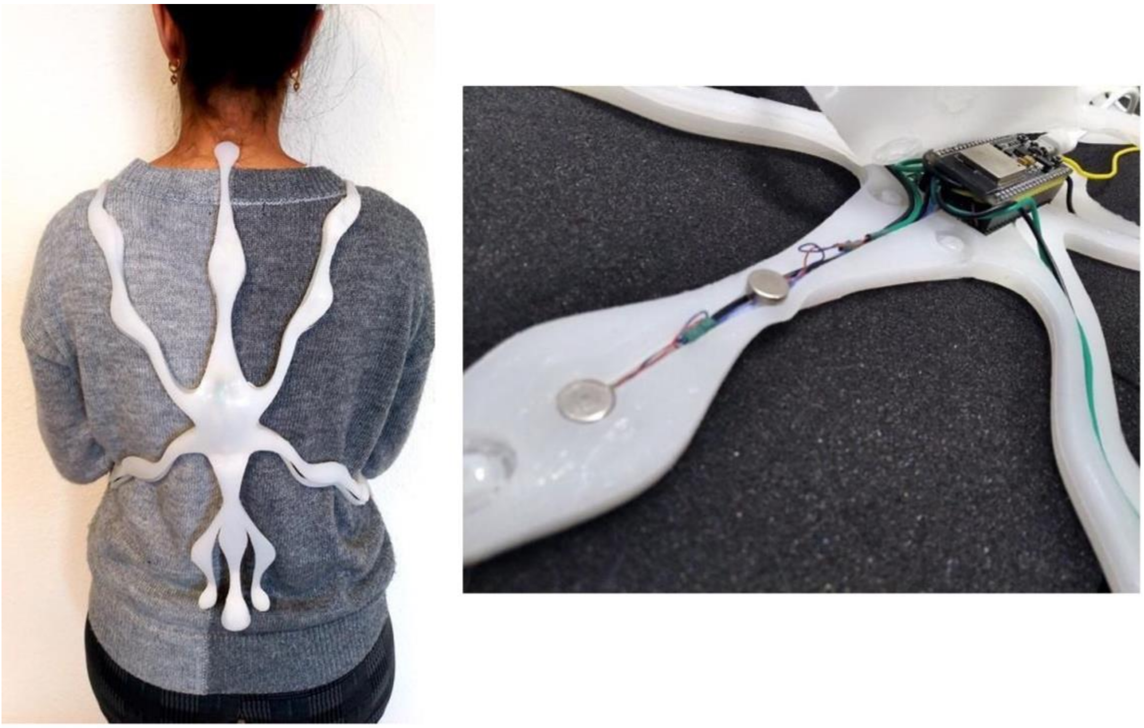

Figure 5: **Prototype to correct posture and facilitate the inner drive to move during PA. The prototype is made of silicon and integrates a microcontroller with an array of transistors and vibrating minimotor discs. The shape and material were chosen to allow placement in different sensitive and relevant body parts, such as the back, chest, or thighs. Vibration could also be configured in different patterns, speeds and frequencies, and could be activated when detecting a particular movement angle or acceleration.**

4 DISCUSSION

The two prototypes exhibit interesting commonalities and differences. Both heavily rely on haptic sensations, delivering vibrations to the back. Interestingly, the technological probes in the workshop were audio based; and while the physicality of the physical probes clearly invited tactile engagement, they also afforded different and more varied physical engagement, felt sensations (e.g., the bubble plastic afforded wrapping around one's body and could have supported BodyS of warm and/or softness), and even using other sensory channels, such as the visual and auditory. This opens questions that could potentially lead to interesting design and methodological implications for future work.

First, it raises the question of why vibration. Is it good tactile feedback? Surely, it is (see e.g. work on Psychohaptics [46]). Further, it is a common choice in commercial and research wearable design [6,18,37]. But precisely because of that, users are quite used to them. Participants can easily understand vibrations, and they find them to be accessible and malleable design materials. But we contend this is in part the reason behind the narrow design space of haptic wearables to support PA. The same argument applies to the choice of haptic feedback instead of auditory feedback. This begs the call for methods to further explore haptic sensations beyond vibration, and other sensory channels, like audio. In the future, we are running dedicated sensory bodystorming workshops exploring and ideating wearables with auditory and haptic feedback, and we will include sensorial sensitizing activities to help participants perceive, understand, access, react, explore and create with auditory and haptic design materials.

Regarding differences, it is worth highlighting the two kinds of PA scenarios that emerged: physical training vs functional PA, which we contend are equally important avenues for design and research. Functional activity is much less explored in the context of wearable technologies for PA, but it is an important source of PA which should not be diminished [13]. These types of activities are valued differently by people with difficulty in PA, and they relate to different barriers to PA they might experience [35]. Further, exercise-gained capabilities often do not transfer to functional activity even if related (e.g., squatting to lift weights or to pick an object climbing stairs) [35]. Hence, it is equally important to address both types of activities to support people with barriers or difficulties to engage in PA.

Moreover, each scenario implements a different design approach for technology design for PA: one focuses on correction, while the other on sensory augmentation. Note that the two approaches were introduced by the naive participants (i.e., facilitators never mentioned them). Interestingly enough, the scenario of physical training implemented the correction approach. This is a mainstream approach in technology design for postural physical rehabilitation and sports (e.g., [11]; see reviews [1,33]). For instance the Upright Go wearable posture device [9,44] is worn on the upper back and vibrates to remind users and correct bad back posture. In turn, the functional activity scenario implemented the approach of facilitating the movement (see [35] for a similar approach with sound). Participants' comments seemed to support that this vibration pattern makes one feel like being "pushed up" or "pushed down." This was similar to the effects observed in Soniband studies using sounds increasing/decreasing in pitch, that when paired with body movement influenced perceived movement ease, as well as proprioceptive awareness and actual movement [19]. This second approach is much less explored, but it is a promising research line as suggested by recent works with sound [19-21,27,35,36,40]. Future work should further investigate this design approach in both contexts, exertion and functional activity, but especially on the latter, since it is underexplored. Each of these contexts may call for a different type of feedback and bodily sensations: e.g. "harsh" sensations calling for attention may suit physical training better, while other sorts of bodily sensations (e.g., comforting, sensual, as if accompanying one) may be more suitable in functional activities.

Last, we conclude with methodological reflections with design implications. First, we pick up again the contrast between the kind of feedback implemented in the ideas (haptic), and the technological probes shown (audio). In retrospect, we realized that participants may have viewed the Soniband device as a complete device and less so a design material, like the physical probes, which may have worked to discourage including/adapting it as part of their design. Nevertheless, we cannot exclude that participants were inspired by the auditory technological prototypes and transferred some of the concepts based on sound to their designs. In particular, one group used "Soniband" with a band around the waist, which was a key design feature in their Design Idea 1. Then, the vibration pattern of Design Idea 2 seems related to the ascending/descending tones in Soniband. Given that vibratory and auditory signals share many physical properties [49], it raises the question of if and how effects in body-perception can be similarly elicited via vibration. In any case, this workshop highlights the potential opportunities opened by haptic/vibratory feedback to raise body awareness and change body-perceptions in the context of PA (see related work [37]).

We conclude by focusing on the 3-step bodymap contribution, which departs from previous depictions [10,21,42] by contextualizing the silhouette at three different moments of a particular movement exercise. Contextualizing in two moments was found useful in [21], enabling participants to better ground particular perceptions/feelings to specific body parts or exercise phases. We found that representing the three moments (before/during/after) movement execution provided valuable insights on the very relevant transformations of bodily feelings, and inspired us to think about interesting design/research directions, such as wearables for physical activation that either disrupt body sensations from "before" phases, or anticipate "during" or "after" phases.

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