Designing for Kinesthetic Awareness: Revealing User Experiences through Second-Person Inquiry

Jules Françoise
Simon Fraser University
School of Interactive Arts + Technology
Surrey, BC, Canada
jfrancoi@sfu.ca

Yves Candau
Simon Fraser University
School of Interactive Arts + Technology
Surrey, BC, Canada
ycandau@sfu.ca

Sarah Fdili Alaoui
ExSitu Team - LRI
Université Paris Sud, Orsay, France.
Sarah.fdili-alaoui@lri.fr

Thecla Schiphorst
Simon Fraser University
School of Interactive Arts + Technology
Surrey, BC, CANADA
thecla@sfu.ca

ABSTRACT
We consider kinesthetic awareness, the perception of our own body position and movement in space, as a critical value for embodied design within third wave HCI. We designed an interactive sound installation that supports kinesthetic awareness of a participant's micro-movements. The installation's interaction design uses continuous auditory feedback and leverages an adaptive mapping strategy, refining its sensitivity to increase sonic resolution at lower levels of movement activity. The installation uses field recordings as rich source materials to generate a sound environment that attunes to a participant's micro-movements. Through a qualitative study using a second-person interview technique, we gained nuanced insights into the participants' subjective experiences of the installation. These reveal consistent temporal patterns, as participants build on a gradual process of integration to increase the complexity and capacity of their kinesthetic awareness during interaction.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous; J.5 Arts And Humanities: Performing arts (e.g., dance, music)

Author Keywords
Movement; Interaction design; Auditory feedback; Sound; Kinesthetic awareness; User experience; Second person interviewing; Qualitative methods.

CHI 2017, May 06-11, 2017, Denver, CO, USA.

http://dx.doi.org/10.1145/3025453.3025714

INTRODUCTION
The ease with which we spontaneously move and act hides a staggering complexity. Even the simple activity of standing in stillness reveals a stream of minute falls and recoveries, the stillness always swaying [33]. A slight bending of the knee for instance triggers a stretch reflex, which in turn brings the knee back and closer to vertical alignment [49]. These are postural reflexes that happen whether we pay attention to them or not.

Bringing attention to these ongoing processes and associated sensations, discloses the intricacy of our embodied experience. Given the growing focus on movement-based interaction, and increasing number of devices being developed, such a realization matters. We value the importance of designing *for* movement and *through* movement [48], with aesthetic appreciation as a driving force [50], to support rich experiences and nuanced qualities of attention to the self [40]. We also consider *kinesthetic awareness* — the perception of our own body position and movement in space — as a necessary condition to ground these design practices, and as the medium through which engaged, complex and generative interactions emerge.

We focus here on designing for kinesthetic awareness. Expert movers, such as dancers and athletes, develop an acute sense of kinesthesia, which supports precise and nuanced movement execution. But kinesthesia also underpins everyday actions and pedestrian activities. This importance is reflected in a wide range of applications, from rehabilitation techniques for athletes [23], to somatic techniques, used to improve balance for seniors [5]. Closer to our research domain, recent studies demonstrate that interactive systems using auditory feedback improve motor learning, performance and experience [3]. We ask then: can auditory feedback also convey kinesthetic information and improve kinesthetic awareness? Does it *speak* to our embodied experience? Furthermore, we investigate how qualitative research methods can help users and researchers access and articulate subjective kinesthetic experiences.

These questions led us to the research-through-design process described in this paper. *Still, moving* is an interactive sound installation created through an iterative and collaborative design process, involving a team with expertise in design, sound art, dance and somatic practices. Using field recordings as rich source materials, the system generates a continuously evolving sound environment, in response to participants' micro-movements and muscular activity. The interaction design leverages an adaptive mapping strategy, refining sensitivity depending on the level of activity. This dynamic adjustment provides users with a sonic 'zoom' into their kinesthetic experience. *Still, moving* has already been exhibited as a public art installation. In this paper, we further evaluate the influence of such auditory feedback on the subjective experiences of users with varying expertise. We contribute to the application to HCI of Vermersch's explicitation methodology [46]. Using 'second-person' interviews, to gain nuanced insights into the participants' subjective kinesthetic experiences. Our results show that participants use highly individualized imagery strategies for generating movement and exploring the feedback loop. Moreover, they reveal consistent temporal patterns, as participants build on a gradual process of integration to increase the complexity of their interaction.

BACKGROUND

Designing (for+through) bodily experiences

HCI's third wave emphasizes a focus on the experiential quality of interaction through phenomenological inquiry [17]. By acknowledging the situated nature of interaction, this paradigm embraces the notions of experience, emotion, expression, meaning-making and aesthetics [8]. The focus is then shifted from a task-driven view of user experience, towards understanding how humans actively create their experience [28]. In particular, the aesthetic experience, as defined in pragmatist philosophy, is a critical value for interaction design research [36]. From a pragmatist perspective, the aesthetic experience "emerges in the interplay between user, context, culture, and history" [50]. It is an intrinsically creative and expressive activity involving a nuanced attention to the body. Numerous approaches to design for bodily experiences have been proposed, such as *Move to get Moved* [21], *Moving and making strange* [25], or *Embodied Sketching* [27].

As argued by Wilde et al., designing *for* movement and *through* movement can enhance awareness to one's self and quality of attention [48]. Somaesthetics intersect somatic practices and pragmatist aesthetics, further recognizing the primacy of bodily movements for being and thinking, as well as the human ability to train and increase their sensori-motor capacities and awareness [44]. Schiphorst introduced somaesthetics as an approach to embodied interaction design [40] that reclaims the lived experience of the body and the 'quality' of an individual's attention to experience. Somaesthetic Appreciation Design, proposed by Höök et al. [20] is a strong concept for interaction design, built around four qualities: subtle guidance, making space, intimate correspondence, and the notion of articulating experience. Our research undertakes a research-through-design approach [51] following these principles, in which we consider intimacy and subtlety as key elements in designing for kinesthetic awareness. Moreover, our design method is based on attempts to articulate lived experience while acknowledging the inherent challenge and difficulty [9].

Kinesthetic Awareness and Proprioception

Kinesthesia, or proprioception, is the sense of one's own ("proprius") bodily perception. Without it we would not be able to walk in darkness, coordinate actions, or even stand. Kinesthetic sensations are integrated from signals from proprioceptors in muscles, tendons and joints [38]. Proprioception operates at multiple levels of motor control. The definitions of proprioception and kinesthesia vary in the literature. Recent clarifications consider that kinesthesia focuses on the sensations of limb position and movement sensing [23], while proprioception includes the aforementioned as well as notions of effort and balance [38]. In this paper, we use the term 'kinesthetic awareness' to refer to the highest cognitive levels and conscious aspects of proprioception: a "part of the somatosensory system that is conscious bodily perception distributed throughout the whole body" [11].

The kinesthetic sense plays an essential role in movement execution. Expert movers refine it by training, to support precision and nuances in their movements. Kinesthetic training is also applied to the rehabilitation of injuries [23]. Practices such as Tai Chi Chuan [16] or the Feldenkrais method [5], can improve proprioception, balance and mobility in older adults. Such benefits are crucial for elderly populations, as losses in proprioception heighten the risks of falls and injuries. Designing for kinesthetic awareness — in particular, providing feedback to support kinesthetic sensing — has a high potential to improve movement abilities and qualities of experience.

Designing Interaction for Kinesthetic Awareness

Proprioception has been applied as an interaction modality in HCI, by integrating movement sensing with electrical muscle stimulation, to support kinesthetic awareness and the memorization of particular hand postures [26]. More conceptual concerns about the importance of kinesthetic awareness have also been formulated, such as reassessing the role of the body as a *medium* beyond its use as a controller [24], to guide attention towards the experience of the body in motion rather than away from the body [30].

The framework of *Kinesthetic Interaction* intersects physiological concerns and kinesthetic experience, to assert the inherent bodily potential as determinant and basis for interaction [11]. Fogtmann et al. derive three design themes from it: 'kinesthetic development' focuses on acquiring and improving bodily skills, 'kinesthetic means' frames kinesthetic interaction as a means for reaching another goal, and 'kinesthetic disorder' implies a transformation of the kinesthetic experience. This is further extended by Cuykendall et al., through the lens of kinesthetic empathy, stressing the importance of physical experience as determinant for the aesthetic experience [6].

Sound × Movement: Skill Acquisition and Experience

While vision is often the preferred modality to support motor learning, recent results show the potential of auditory feedback for improving sensori-motor learning, performance, and experience [3]. Sonic Interaction Design (SID) considers the use of interactive auditory feedback to enhance, alter or extend object affordances and their manipulation [14, 39]. Similarly, continuous auditory feedback responding to a dancer's movements can foster movement exploration and support learning [12]. With Sarka, Bergström and Jonsson proposed an interactive sound installation aiming to increase bodily awareness and assist relaxation [2]. Following the principles of Somaesthetic Appreciation Design, Sarka maps subtle changes of pressure on a mattress to the amplitude of various environmental sounds.

With *still, moving*, we align with this body of research through the specific lens of kinesthetic awareness, using auditory feedback to support it. Sound has a unique capacity to convey rich subtle content, while imposing a low cognitive load, compared to vision. It also does not interfere directly with proprioception, as vibrotactile feedback or muscular stimulation do. The design of *still, moving* involves mainly the movements and muscular activity of the lower legs, within related activities of standing, walking or dancing.

Works addressing balance or walking often make use of force sensing resistors to capture user interaction [47, 10]. Given our focus on kinesthesia, we chose electromyography (EMG) to access subtle muscular activity in the lower legs. Interactive audio applications using physiological sensors have a long history in the field of New Interfaces for Musical Expression (NIME), such as Tanaka's BioMuse [45] or Donnarumma's XTH [7]. Francoise et al. proposed a movement sonification system based on EMG and inertial sensors, to support dancers' learning of specific somatic techniques [12].

DESIGN PROCESS

Still, moving was created by a team with expertise in design, sound art, dance and somatics. The second, third and fourth authors bring years of practice in contemporary dance and somatics. The first and second authors are experienced in sound art and design. Our research-through-design process [51] relied widely on autobiographical design [31], with constant exchanges between designing interaction, curating movement and designing sound. The design process was grounded in the studio as a shared space of experimentation allowing the expression of the dancers' 'somatic connoisseurship' [41].

Initial Design Constructs

We initiated the design with a phase of ideation between all researchers, starting from the premise: "there is no stillness in human movement". Even while standing still, the body is constantly moving, falling, catching up, and subtly adapting to the environment [22]. This ongoing flow of involuntary activity unfolds mostly unseen and 'unfelt'. The artwork's initial goal was therefore to reflect and extend inner bodily experiences by revealing these hidden processes through sound.

A deep attention to kinesthetic experience reveals the complexity and expressive power of these *micro-movements* [10, 32]. The very act of standing is only possible because of repeated muscular contractions, to restore the body's balance against the pull of gravity, or anticipate large voluntary movements [15]. To access these nuances at the physiological level, we used electromyographic (EMG) sensors: a pair of Myo[1] devices, placed on the lower legs, to sense the musculature of the calves and shins. We chose walking as a primary movement pattern because walking is a complex movement requiring balance, coordination and weight shift, yet is accessible to a general audience.

Design Practice in the Studio

We started prototyping readily after a rapid brainstorming phase, to create an initial set of metaphors. For three weeks, we engaged in regular design sessions in a dance studio. This environment fostered creative movement exploration and allowed for rapid iterations over design prototypes. We report in this section a set of key aspects of this collaborative process.

Qualities of Attention

The studio provided a space for experimentation, as a physical space as well as an intimate environment for sharing lived experiences. Discussing design ideas and evaluating existing designs is obviously important, but first and foremost is sharing movement experiences. As stressed by others, engagement *through* movement practices is central to designing *for* movement [48, 40, 27]. We further this notion by considering *qualities of attention*, implying a deep attention to one's own movements and senses, and extending this awareness to one another in the collaborative process. Giving each actor the possibility of iterating through experiencing, observing and communicating experiences, fosters creative explorations.

Live-Coding Interaction

We iterated on the prototypes rapidly, implementing new features in between sessions, but also during the sessions themselves. Explorations often yielded surprises, such as unexpected connections between sounds and gestures, which we worked to capture and unpack in the moment. In music, live-coders improvise computer music through real-time scripting during live performances [4]. In our process, we developed a similar practice of *live-coding* movement interactions. Motion-sound relationships were programmed in real-time, exploring mapping variations, or capturing, processing and recognizing some of the performer's movements. We made particular use of interactive machine learning [13] to record, recognize, and associate walking patterns to different sounds in real time.

Capturing Incidents

We explored in the studio a large variety of movements and prototypes. These creative explorations allowed us to evaluate given designs, but also revealed unexpected outcomes. Such critical *incidents* take a variety of forms: a given gesture accessing the sonic space in a surprising way, a new set of sound inspiring further metaphors, or a particular tweak of the mapping revealing unexpected possibilities.

One of these incidents, emerging from the use of EMG sensors, eventually became essential in the final installation. EMG measures the tension resulting from random depolarizations of muscle fibers. Because this measure is taken through the skin, individual variations are high, depending on skin thickness and conductivity. The usual solution is a fixed scaling of the

[1] http://myo.com/

dynamic range, from an initial calibration measuring maximum muscular contraction [18]. Such a calibration however was problematic in the context of a public art installation.

Our solution implements an adaptive mapping strategy to scale the sensitivity of the system dynamically, depending on the level of muscular activity over a time window. This practical solution to an issue of *inter-personal* variations, opened a new space for examining *intra-personal* contrasts. For example, walking or jumping would calibrate the system to a wide dynamic range. But standing still would gradually increase the system's sensitivity, eventually sonifying every slight muscle contraction involved in balancing the stand. This adaptive property is now central to the final design: an auditory 'zoom' into one's kinesthetic experience of micro-movements. Adaptive mappings have already been proposed in the NIME community [29], for example for improving the accuracy of pitch control on touchscreens for expressive vocal synthesis [35]. Often, these mappings are designed for fine-grained control of musical instruments by expert performers. In this work, we focus on novice users with an adaptation strategy that slowly evolves to increase the system's sensitivity to micro-movements.

THE STILL, MOVING INSTALLATION

Still, Moving was initially conceived as an art installation, and was premiered in March 2016 in New York, within the scores+traces collective exhibition. We now describe briefly the interaction scenario of the initial artwork. Then, we describe in more detail one sonification strategy, the most relevant to kinesthetic awareness, which we evaluate in this paper.[2]

Interaction Scenario of the Initial Artwork

The design process converged towards a multi-layered sonic interaction scenario, where several modes can be accessed through different types of movements (See Figure 1). As soon as a user starts walking, the frequency and energy of the walking pattern is computed to generate a texture from overlapping fragments of urban sound recordings. As the frequency of the walk increases, the urban environment gains presence and noisiness. The limited possibilities of interactions at high energy were meant to invite the participant to a quieter state, in order to explore more nuanced kinesthetic sensations.

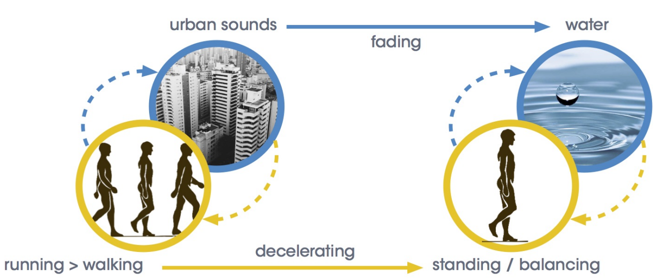

Figure 1. Schematic representation of the interaction scenario of *still, moving*.

As the user slows down, the urban atmosphere fades into a quieter environment, based on recordings of water, rustling leaves and other organic materials. The force of each step, as captured by muscular activations in the lower legs, continuously controls sound synthesis. As the user settles into stillness, sound variations become more nuanced, zooming in to reveal minute postural changes. The sound grains move in space, following weight shifts from one foot to another.

Figure 2. A participant interacting with the *still, moving* installation. The Myo devices are capturing muscular activity and motion to generate the sound environment

Technically, the complete installation included mappings using acceleration and muscular information, binaural spatialization, and walking pattern recognition. Yet, we identified that the sonification of muscular signals as the most relevant for kinesthetic awareness. In the remainder of this paper, we focus on describing and evaluating a single mapping strategy: an adaptive mapping based on muscular activity to control the synthesis of environmental sounds.

An Adaptive Mapping to Sonify Subtle Force Variations

The main mapping strategy of the installation is described in Figure 3. Two Myo sensors are placed on the participant's calves. Muscular information is processed by extracting the force from each EMG channel (Figure 3, (1)). We used a bayesian filtering technique similar to those used in prosthetics control [18], that is both more stable and more reactive to rapid changes than techniques based on a smoothing window. The force is then rescaled using an "adaptation level" computed as the maximum of the force over a sliding window over the past 10 seconds (Figure 3, (2)). This *adaptive* process is continuously updated during the interaction, providing a kinesthetic 'zoom' where the system's sensitivity increases as the extent of movement decreases. For each leg, the muscular information is then reduced to two channels that approximate the force on the calf and the shin, respectively.

The force from the calf is mapped to the synthesis of a sound texture of water recordings with varying timbre. A similar strategy is used for the shin, for organic textures of rustling leaves and brushing sounds (Figure 3, (3)). Technically, the instantaneous force (normalized to the adaptation level) is mapped to the loudness (normalized over the sound corpus). The loudness parameter then controls descriptor-driven, corpus-based, concatenative sound synthesis [43]: the loudness value is used to retrieve sound 'grains' from the corpus of water sound with matching intensity. As a result, while the

[2]supplementary material is available online:
https://www.julesfrancoise.com/stillmoving

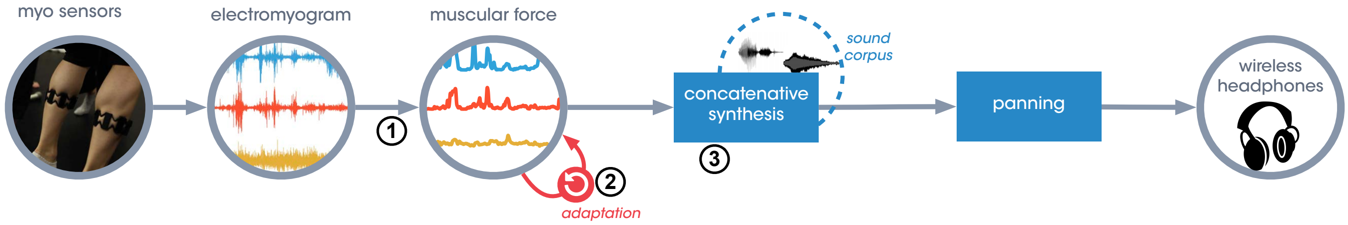

Figure 3. Synthetic architecture of the *still, moving* system. (1) the muscular activity is captured by EMG using Myo sensors, and the force is estimated using bayesian filtering. (2) The force is rescaled using on-line adaptation. (3) The force controls the concatenative synthesis of environmental sounds.

sensitivity to muscular contraction varies with the adaptation, the correspondence of force-to-loudness remains consistent at all times. In order to increase the transparency of the adaptation process, we added a direct mapping from the adaptation level to a pitch-shifting transformation of the sound samples. As the force level globally decreased, the pitch of the sounds increased, to illustrate the change of sensitivity. The left and right legs were processed independently, and mixed in a left-right panning.

We chose environmental sounds because of their evocative power, that resonates with our auditory experiences in the real world. We iterated over recording, selecting, and testing the sounds with the interactive system. We took particular care to build the sound corpus so that loudness variations result in consistent and rich variations in timbre. This allows the participant to navigate a complex sound space with the sole loudness parameter, mapped to the force.

REVEALING USER EXPERIENCE THROUGH SECOND-PERSON INQUIRY

We conducted a study investigating how auditory feedback affects a mover's experience, and particularly his/her kinesthetic perception. The study aims to observe and articulate if and how the proposed design can convey kinesthetic information and influence kinesthetic awareness; while also informing further developments of the system. We elicited feedback both from skilled dancers and non-dancers through semi-structured interviews following phases of open and guided interaction with the system.

Participants

We recruited 12 participants through our university mailing list, half of which are expert dancers (college to professional experience), the other half are novices. Age ranged from 21 to 36 (mean=26, STD=4.3), 10 participants were female and 2 were male. Participants were compensated for their time. The group included a diverse range of movement backgrounds, which we discuss below.

Apparatus and Data Collection

The experiment took place in a dance studio at Simon Fraser University. We used a reduced version of the *still, moving* system previously described, which included only the interaction with natural sounds based on EMG. Participants were ask to wear a Myo[3] device on each calf. We recorded the 2x8 EMG data streams from both devices, measuring muscular contractions of the muscles of the lower legs (including the soleus and the tibialis interior), as well as inertial measurement data. The session was video recorded. Both the interactive system and the motion capture were implemented using Cycling'74 Max 7 and the Mubu library [42]. Both audio and video was recorded during participants' interviews.

Protocol

Participants were first equipped with the two Myo devices, and given an oral description of the experiment. We specified that the sound was generated in response to their movements and muscular activity, without further details on the mapping strategy. Participants were instructed to move freely with the interactive auditory feedback, while paying attention to the sound and to their own body sensations. The session was divided in three phases of interaction:

1. **Open non-facilitated interaction 1:** Dancers were invited to freely explore the interactive system through movement, without guidance or facilitation.
2. **Facilitated Interaction:** Following the open interaction, a second phase was facilitated by one of the experimenters. Mindfulness exercises such as Steve Paxton's *Small Dance* [34] were used to bring attention to involuntary micro-movements, and the sensitivity of the auditory feedback system to such minute shifts.
3. **Open non-facilitated interaction 2:** Dancers were again invited to freely explore the interactive system through movement, without guidance or facilitation.

We conducted a semi-structured 30-minute interview with each participant, directly after the interaction session.

Second-Person Interviewing

The semi-structured interviews were based on Petitmengin's *explicitation interview* [37], a form of phenomenological inquiry developed to access and articulate subjective experiences. Petitmengin's method was developed from the seminal work of Pierre Vermersch on explicitation [46]. Interviewees tend to initiate their recollections with general statements, and this methodology is designed to facilitate a process of getting deeper and closer to *singular experiences*. It is thus ideal for our aim of eliciting fine grained descriptions from the participants: on their experiences during the interactions, regarding the auditory feedback, perceived connections with their movements, strategies of exploration, and their kinesthetic awareness.

[3] http://myo.com/

To alleviate the difficulty of describing one's own experience, Petitmengin mediates the first-person point of view of the interviewee through the second-person perspective of the interviewer. The challenges of relating first-person experiences emerge from several factors such as the dispersion of attention, the focus on the task at hand rather than its process, a tendency to confuse lived experiences and their representations, and the variety and granularity of the dimensions of attention. Explicitation interviewing has been applied to the analysis of subjective experiences of data visualization, resulting in nuanced descriptions and rich narratives [19]. The explicitation interview employs a number of strategies to elicit first person experiences [37]: 1) stabilizing attention, 2) turning the attention from 'what' to 'how', 3) moving from a general representation to a singular experience, 4) retrospectively accessing the lived experience, 5) directing attention to the various dimensions of the experience, and 6) deepening the description to the required level of precision.

These considerations are particularly relevant to retrieve somatic experiences. Our movement awareness tends to be holistic and goal orientated, rarely considering the *means whereby* we do what we do [1]. Standing on one leg, we seldom pay attention to the position and force of all body parts that enact our balance. The deepening of attention necessary to become aware of these sensori-motor processes, is just what the explicitation interview fosters. The process naturally sifts through the flow experience to converge towards *singular experiences*. During the interviews, we followed the above guidelines to reveal sensible details of each user's experience. We systematically selected singular experiences, e.g. particular gestures or sensations, from the observation of the participant's interaction and the participant's discourse. We often invited participants to revisit or even re-enact this singular experience, to gain access to the various dimensions of attention and sensory perception.

Analysis

We transcribed, then analyzed the interviews using a grounded theory approach. The two researchers who conducted the interviews coded the interviews. We developed the coding system through initial discussions, individual coding, and through a final negotiation between the coders. Given our focus on experience, our coding system included references to sensations, shifts of attentions and intentions, modes of explorations, appreciation of the feedback loop, attention to micro-movements, or reflections about body and movement induced by the interaction.

FINDINGS

As mentioned, our group included participants with a diverse range of movement backgrounds: yoga, Tai Chi Chuan, contemporary dance, Alexander Technique, or no specific movement background. Accordingly, they relied on different movement repertoires as the basis for their explorations, from pedestrian activities to more technical patterns. Interestingly, through the lens of *subjective experiences* and *qualities of attention*, the general types of movement repertoires did not matter. Because the system was designed to reflect small shifts and micro-movements, we observed as much nuances in the sounds generated from subtle variations of walking, as from more elaborate dance movements. Similarly, the richness of the participants' insights had more to do with their engagement and curiosity than their movement backgrounds. In the remainder of this section, we report the findings for the entire group, regardless of participants' backgrounds.

Given the semi-structured nature of the interviews, we followed a non-linear path to retrace the 'story' of each participant's interaction. Moving from general impressions towards detailed accounts of singular experiences, we revisited the evolution of her/his thought process along the arc of the interaction. We identified both shared and singular accounts of changes in kinesthetic awareness. Consistently, a set of first images and expectations created an initial disconnect in the experience of the feedback loop. Participants mainly resolved this initial disconnect through exploration and sense-making strategies combined with the facilitation. This learning process then evolved towards deeper levels of kinesthetic awareness.

Exploring the Feedback Loop

As expected, participants engaged in an exploration of the system's behavior, by trial and error, in an attempt to "decipher" or understand the relationship between particular movements and the auditory feedback.

> Just choosing to see what sounds would be the results of my movement choices, moment by moment... to focus on that task... Whether it was something as simple as taking a step forward or lifting up my leg. (P1)

Nonetheless, this exploration went further than merely evaluating the output generated from given inputs. The sound often supported the inspiration for further movements, inducing a *"back and forth, a dialog between what I was hearing and how I was responding to it."* (P1) Participants were fundamentally situated in a complex feedback loop inducing a constant interplay between several sensory modalities (auditory, but also visual and kinesthetic).

> Sometimes I'll pay more attention to the sound itself... And then I'd forget about my body a little bit, and then I'd just kind of focus on listening to sound and then sometimes I'm like: "'okay, I'd kind of take what I just heard, and I'd try to, like, reflect it and then experiment with my body." And then the focus kind of shifts back to my body. (P7)

Descriptions of exploration strategies often highlight nuanced and shifting qualities of attention to these lines of feedback.

> OK, so now I am moving, I'm just shifting my weight, I am noticing the architecture of my feet, and this sounds a certain way. (P1)

Imagery as Strategy for Sense-Making

Very consistently, participants reported rich imagery evoked by the sounds of water present in the auditory feedback. Although this immediate recourse to imagery for sense-making is not surprising, it came in a variety of modalities and individual relations to past experiences. These specific reactions were also translated into specific approaches to make sense of the feedback loop through movement.

View Points

First, all participants reported strong visual images, emerging with different view points: either without mention of an observer, or with marked allocentric or egocentric perspectives.

> The first image that came into my mind from... the sound, was just like that [moving fingers] that brook, that like rushing water, like speeding over rocks. (P8)

> There is like a camera upward and it focuses on you [...] I think it was pretty much that scene, the visual of the movie, but instead of the actor I was trying like slowly walk on the water. (P2)

> No, it was definitely an image. It was definitely like... Yeah, I felt like I was looking out at, like, an ocean. (P4)

Sense Mediation

Second, imagery was sometimes mediated by other senses than the visual modality, with mentions of auditory, kinesthetic or tactile sensations.

> But sometimes if I did it very gently, played with the toes, it just sounded like rustling leaves. (P5)

> I just listen to the sound, and it feels like I'm swimming, but I don't have that image in my mind. (P6)

> It's like: "I'm walking in shallow water and exactly I'm trying to kind of push the water forward with my leg." (P3)

Interplay with Memories

Third, the images emerging from the sound's evocative qualities often interacted with memories of past experiences. These memories could take a variety of forms, from vague or habitual impressions to singular memories.

> Yeah, I mean, immediately, like, waves slapping at the shore, at a beach... Like, that brings up many memories for me of, like, many times being at beaches... (P4)

> We had... as a kid... I don't know, for some reason the construction of our house was going on for a long time, and then like... We are used to use wood here, we used to use bricks like, back in India and we used to soak them with water... (P2)

Strategies for Movement Generation

Finally, imagery as a sense-making process was crystallized by the subtlety of strategies for generating movement from particular images. While some participants engaged in mimicking the image coming from the sound, others employed metaphors such as *"I'm hearing water I will be water."* (P5). More elaborate strategies involved (re-)enacting a given image, or even imagining how to further it, how to *"continue the story."* (P9)

> There was actually some instances where I imagined I was actually in the beach, in the sand. And then I was like: "don't worry about, kind of, mimicking and translating that wave movement through my body, what if I was in the space itself?" How would I... What would it be...? So, how would I move through the water itself? Like, I'd be splashing, but what if I do some movements in the water... Imagine how that would feel. (P7)

The Interactive Experience over Time

Any interaction is fundamentally temporal. Interacting requires engaging and learning. In this section, we analyze shared pathways of experience and exploration along the movement session. This evolution involves an initial disconnect and its resolution, the appreciation of subtlety through facilitation, and the expansion towards more complex kinesthetic experiences.

An Initial Disconnect

First, even though the participants were informed prior to the movement session that the system is interactive, and the sound is generated from their movements, one of the most consistent finding is an initial feeling of disconnect.

> I tried to find that out by... first not doing any big gestures. But it didn't seem to connect, at least in my perception, of anything of my own volition. That the sounds were, I heard the sounds of the water, but I didn't feel I controlled the shape or the arc of the sound, through my movements. (P9)

Several factors contribute to this disconnect, such as the use of muscular sensors, which can be difficult to apprehend in relation to movement, the high sensitivity of the mapping, or even personal biases and expectations.

> The very first impression was I had no idea where the sound was coming from, because... I almost thought that it was happening... like, that it was really delayed to my movements, like, I could kind of hear that it was reacting to me, but it sounded very delayed... And then I soon realized that it's not delayed. (P5)

> I guess, probably because of my training and some other reasons, I suspect, it didn't register that those sounds were readings, sonic readings of my movement that was being picked up by the devices, for whatever reasons. [...] In other words, I think I had forgotten that those sounds were in response to what I was doing. (P1)

Reconnecting

Second, 10 participants experienced a resolution of the initial disconnect during the movement session, and 2 participants reported a feeling of disconnect that persisted throughout it. Most participants experienced a reconnection during the first open exploration or during the facilitated interaction. This sense of connecting, or integrating the feedback loop, can either result from the accumulation of implicit understanding of the mapping, or can emerge as a singular experience that shifts a feeling of urgency to a sense of control.

> I remember, in the beginning, I hear the sound, it... it has some kind of heartbeat in that, and it's a very fast-paced, so I feel kind of anxious about it, and the sound... the watering is very... a little bit loud so... I just keep on walking and walking... and... and then I think there must be something in it, so... I try to explore using my arms, using different kind of movements, and then... maybe

> because I changed my pace or something, I found the sound can change. (P6)

> And once I finally just kind of let go of my anxiety and like moving more... And exploring the space and just kind of getting used to the sound, it was like: "oh, it's linked to my movement and like, the type of movement, or how fast or... or directionally." I think that, that once I felt like I had control, it was more relaxing. And that happened, I think, probably towards the last half of the first session. (P10)

Facilitating Attention to Micro-Movements

The second phase of the movement session was facilitated by one of the researchers. This facilitation contributed to trigger or increase the participant's recognition of the movement-sound relationship. By inviting a simplification of movements towards standing, and by directing the focus towards the exploration of kinesthetic sensations, the facilitation contributed to sharpen the participants' appreciation of the system's subtleties towards micro-movements.

> After being guided through the small dance with you, I guess the subtleties of my movements became more apparent, because I didn't have to move so much to be able to hear how there is sort of a lot going on, just from what I can tell by the sounds, a lot going on in terms of my musculature, without actually moving large. (P1)

> I found myself wanting to distill the noise. But, now thinking about it, it's so reflective of what you were talking about with the Steve Paxton dance. That, like, there is that much activity going on in your body. And I think it really drew my attention to that. Cause even when you think that you are still you are of course moving and making small adjustments. (P8)

Complexifying through Whole-Body Connectedness

In the final stage of interaction, the open exploration following the facilitated phase, participants extended their attention to micro-movements and nuanced sensations into other body parts, more whole bodied movements. Most participants reported an increased awareness of their body's connectedness.

> The couple times that I was using arms swinging, that was the only... only small time that I was consciously thinking: "Ah-ha, my arm is doing this but it's still making sound." And knowing that... knowing that it was not my arm, but it was the force that my arm is sending to my feet. (P5)

> A big sound came at one point and I was confused, cause I felt like I hadn't made that big of shift in my body. [...] And then I think just realizing that... the like echoes throughout your body, that like such a small adjustment can make and that... trickle up. (P8)

The system's reflective power is highlighted by participants' reflections upon their own bodies. We collected detailed explanations of mechanisms such as balance, weight distribution, or even the interplay between bone structures and muscles in supporting weight shifts.

> At the very beginning, I though: "it's not really capturing the weight, it's just capturing the muscle". So, if I have my weight, it could just go through my bones, right? It's not like... My muscles would be completely relaxed. (P3)

> When my eyes were closed I didn't have to try to do anything, things just happened. My weight shifted, I didn't... But when my eyes were open, I was like: "come on, make a sound, why is nothing happening?" So I have to try to make a sound. Maybe because I have poor balance when my eyes are closed, so my weight is shifting. (P5)

Singular Experiences

Each participant brought a very personal perspective to the interview, often involving a recurring theme accentuated in one or several 'singular' experiences. In this section, we report and analyze two of these singular experiences.

Participant 5

Following a pause, with eyes closed and gesturing:

> Oh yeah! When I am doing this [standing on one leg], and then when I start to fall forward and my weight shifts onto the ball of my feet a lot a lot a lot a lot a lot! It's... It was just perfect... and I... I felt like a wave. I... And I kind of expected the sound to stop, when, I like, truly felt but... I guess, it continued In a natural way, like a actual wave. I thought it would just kind of stop, but the wave rolled on. [...] But waves really do roll and fall and catch themselves, so that that type of movement I guess felt really natural with the sound... Integrated. [...] Yes, definitely 100% I felt like my body was continuing, even though it wasn't. and it's actually only now that I look back at it that it's such a stark contrast between what I was doing and what the sound did, but in the moment I felt like I continued as well. [...] I felt like there's water pouring out of my face. So... Fall, and then the water that I could see was, like, a continuing that sound. (P5)

The singularity of this particular experience was revealed by P5's re-enactment and strong reaction to the memory when it came to her. Her experience is initiated by a specific movement, but the strength of the experience seems to originate in the congruence, in this very movement, of multiple sensory modalities. Together these modalities create a synesthetic experience (*"I felt like a wave"*) of such strength that it induced a kinesthetic illusion (*"I felt like my body was continuing, even though it wasn't."*). The multisensory integration between the dynamics of the movement and the sound, colliding with the underlying metaphor of a wave falling and its visual representation, induce an altered kinesthetic state.

Participant 9

> When my hips went back, and I was lower to the ground, and as if my head was moving against the the... what to my mind was like the pressure of the water making the sound. And obviously I was underwater, and taking... some air. And then going even lower to the ground and feeling the texture of the floor. But then pulling in my memories of what it was like being underwater. (P9)

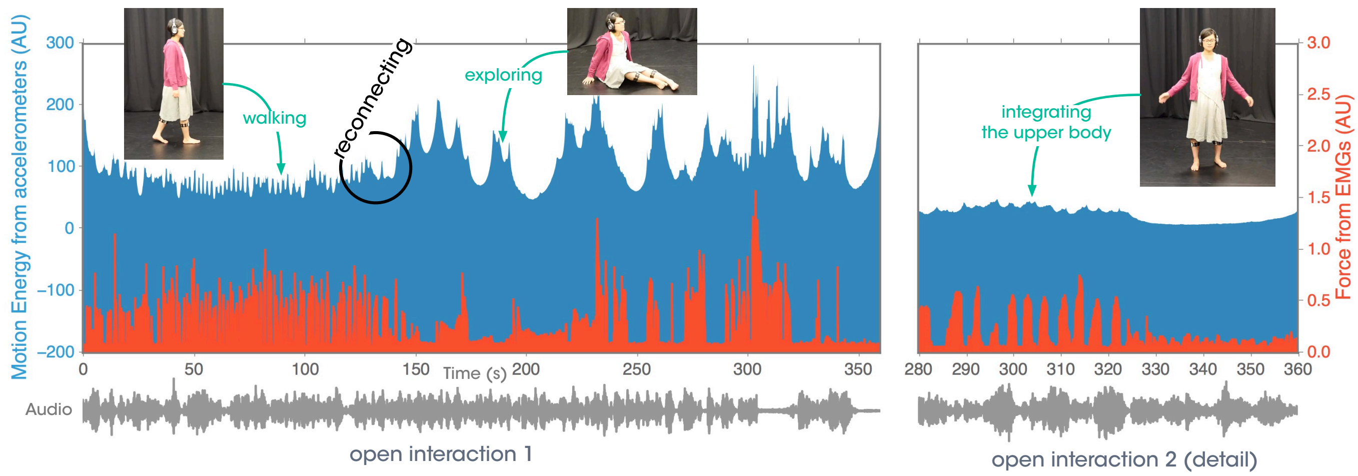

Figure 4. Analysis of Participant 6's movement interaction. Blue areas denote the energy of the movement of the left leg, computed from the accelerometers, red areas represent the force captured by the EMG on the left leg. The annotation is informed by the qualitative analysis of Participant 8's interview.

P9 presents a similar account of an integrative experience where the kinesthetic experience collides with rich and articulated imagery. As for P5, the description is initiated from a particular movement and follows with a collision of kinesthetic and tactile sensations, with a strong image of being underwater, and experiences of weight or pressure, and needing air.

Tracking Attentional Shifts in Sensor Data

Through the case study of P6, we present an interpretation of the sensor data informed by the qualitative analysis of her interview. Figure 4 reports the temporal evolution of the energy of the motion and the muscular contraction of the left leg, over the first open session, as well as a detail of the end of the second open session.

Attentional shifts in the first exploration are clearly highlighted by the changes in motion energy. P6's interview provides an interpretation for the change from a repetitive pattern to more nuanced variations in the sensor data:

> I remember, in the beginning, I hear the sound, it... it has some kind of heartbeat in that, and it's a very fast-paced, so I feel kind of anxious about it, and the sound... the watering is very... a little bit loud so... I just keep on walking and walking... and... and then i think there must be something in it, so... I try to explore using my arms, using different kind of movements, and then... maybe because I changed my pace or something, I found the sound can change. (P6)

The participant then engages in a rich movement exploration, finding placements on the floor that isolate sources of movement from muscular contractions. After the facilitation, she further complexified her interaction by integrating the upper body. The right part of Figure 4 highlights very low movement levels, with consistent and cyclic muscular patterns. As the contraction diminishes, the mapping adapts to these low thresholds and generates a sensitive response to her micro-movements. Her insights further clarify her intention, and the benefits of the sound in increasing her somatic connoisseurship:

> At first I just want to move my arms to see if there is some changes, because in my previous understanding, maybe chang... Moving your arm cannot change what you are standing, but in this system I found that even a slightly change of my body position can reflect on my leg muscle. (P6)

DISCUSSION

We discuss in this section the singular aspects of designing for kinesthetic experience. This reflection is informed by both our design process and the analysis of our design choices under the lens of participants' experiences. We also provide insights into the benefits and potentials of the second-person interviewing technique for eliciting first-person movement experiences.

Designing Inside the Feedback Loop

Design research methods have produced a variety of powerful tools for generating design ideas including, in the case of movement interaction design, bodystorming, somatic training [41, 20], or embodied sketching [27]. Yet, beyond design concepts, implementation is essential for continuous interaction: moving *in interaction* is fundamentally different from *sketching* or *simulating* interactions, as it positions the user within a singular action-perception coupling. It is essential to practice design 'inside' the feedback loop, to explore the space of variations in the implementation of the mapping. Often, we do not have at hand a single criterion to find the 'optimal' design — e.g. an ideal sound design or mapping function. We must embrace the uncertainties of exploration, through movement and using deep attention, until singular experiences reveal themselves in the design space through incidents and discoveries. Making space for exploration during the design process, using nuanced qualities of attention, is essential to capture and unpack these 'Aha moments' that reveal singular experiences within the exploration of design concepts.

Problems and Prospects with Adaptive Systems

The final design of *still, moving* leverages an adaptive mapping strategy that constantly refine the sensitivity of the system as interaction progresses. This adaptation process is simple: the systems keeps track of past energy levels over a short-term memory to scale its sensitivity. The resulting acuity raised participants' awareness of their micro-movements:

> I had noticed that I had imagined moving, but not moving, just thinking about it, that I heard all these sounds, so there is actually... I understood that there was movement already happening, just from my thinking, envisioning. (P1)

This adaptation implies that the sound generated at a given instant is conditioned on the history of the interaction. Consequently, phrasing gestures goes beyond the mere sequencing of sounds over time. The effect of a particular gesture depends on the previous gestures in the sequence, which enriches the interaction possibilities.

Obviously, this expressiveness comes at the cost of a steeper learning curve. The extreme sensitivity of the system has certainly contributed to the initial disconnect experienced by the participants. Even though the final system included a translation of the adaptation parameter itself in a sound transformation, the inherent complexity of understanding time-evolving behaviors requires time and engagement. We speculate that the reason why most users managed to appropriate and play with the installation is that while the sensitivity evolves, the interaction metaphor remains consistent with a congruent mapping between force and loudness. Further developments will focus on increasing the transparency of such adaptation processes, to facilitate expertise acquisition.

We designed the study to speed-up the exploration of the feedback loop and the understanding of the adaptation process. From the presentation of the system as a public art installation, we had observed that participants rarely spontaneously explore stillness and slow swaying motions as modes of interaction with new technologies. The phase of facilitated interaction was designed to draw the participant's attention to micro-movements where the adaptation of the sensitivity became clear. We need to further investigate how other modalities can facilitate the learning process of a particular interactive system. For instance, verbal guidance could be pre-recorded, and adaptively replayed according to the participant's mode of interaction. Alternatively, we could imagine to further complexify the mapping so that the auditory feedback seamlessly guides the participant.

Accessing Kinesthetic Experiences at the Second Person

Various qualitative methodologies exist for accessing user experience. For instance, we could have used video recordings of the participants' interaction as a support to guide the interview and facilitate access to memories. However, our goal was to get detailed accounts from users as close as possible to their first-person kinesthetic experiences. Yet, the third person perspective of the video recordings might already distance them from their inner experience.

We chose to conduct interviews following Vermersch's explicitation methodology [46], which aims to extract individualized first-person experiences of singular activities. This methodology has a tremendous potential for investigating movement experiences, and more broadly for experience inquiry in HCI. We employed a number of processes detailed by Petitmengin to help interviewees focus on their actual experience [37]. We tried, as much as possible to use short and focused questions about each participant's experience. Very often, singular experiences emerged early in the interview from the participant's discourse, and we sometimes stimulated this identification from our own observations of their interaction. Once we identified a singular experience, we gradually increased the level of detail of the questions, from the description of their movements and postures towards the various sensory dimensions (auditory, visual, kinesthetic) and their attention and goals. We tracked the emergence of first-person revisitations of singular experiences during the interview process, using nonverbal and para-verbal cues. For instance, a participant would become silent, look up or close the eyes, and finally start speaking at the first person, in the present tense, highlighting the reenactment of a singular experience (See for example P5's singular experience).

Not only did it allow us to elicit detailed accounts of physical sensations and attentional mechanisms, but it often stimulated participants to reflect on their own experiences and, by extension, on their bodily awareness.

> So when I'm standing on the floor, I don't really feel like I'm activating any muscles in my feet, but I guess I must be, because when I simply touch my feet they're not activated, but no sound happens. So maybe it's not the pressure but it's just the activation of the foot muscles... So I think I'm just discovering that now... (P5)

CONCLUSION

This paper contributes to a better articulation of kinesthetic awareness as a critical value in embodied interaction design. *Still, moving* illustrates and unpacks a design methodology addressing the challenge of creating rich and nuanced aesthetic experiences to stimulate creativity and increase bodily awareness. The tremendous richness of participants' accounts of their interaction with *still, moving* underlines that aesthetic movement interaction can increase kinesthetic awareness and somatic knowledge if it is designed to foster a gradual process of integration and complexification of the experience over time. Our choice of an evocative sound design, for instance, resulted in elaborate meaning-making strategies based on individualized imagery to explore the action-perception loop. This consideration is crucial for applications in health and wellbeing that use feedback to guide or correct particular gestures, and where simplistic auditory feedback is common. More than merely making the experience enjoyable, aesthetic values in interaction design are critical to support complex interaction, self-reflection, and skill acquisition.

We contributed to the application of second person inquiry to access subjective first person kinesthetic experiences. This methodology, developed by Vermersch and well formalized by Petitmengin [37], has a tremendous potential for articulating technology as a lived experience. Not only does it allow researchers to get detailed insights of singular user experiences, but it also contributes to increasing users' awareness and understanding of their own experiences and cognitive processes.

ACKNOWLEDGMENTS

This research is supported by the movingstories project with financial support of the Social Sciences and Humanities Research Council of Canada (SSHRC partnership grant GT 15152). We thank all the study participants for their involvement and feedback, and we acknowledge all the members of the movingstories consortium for fruitful discussions.

REFERENCES

1. Frederick Matthias Alexander. 2001. *The use of the self*. Orion Publishing, London, UK. Book, Whole.
2. 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 Press, Thessaloniki, Greece, 1–8. DOI: http://dx.doi.org/10.1145/2948910.2948922
3. Frederic Bevilacqua, Eric Boyer, Jules Françoise, Olivier Houix, Patrick Susini, Agnes Roby-Brami, and Sylvain Hanneton. 2016. Sensori-motor Learning With Movement Sonification: A Perspective From Recent Interdisciplinary Studies. *Frontiers in Neuroscience* 10 (2016), 385. DOI: http://dx.doi.org/10.3389/fnins.2016.00385
4. Nick Collins, Alex McLean, Julian Rohrhuber, and Adrian Ward. 2003. Live Coding in Laptop Performance. *Organised Sound* 8, 3 (dec 2003), 321–330. DOI: http://dx.doi.org/10.1017/S135577180300030X
5. Karol A Connors, Mary P Galea, and Catherine M Said. 2011. Feldenkrais method balance classes improve balance in older adults: a controlled trial. *Evidence-Based Complementary and Alternative Medicine* 2011 (2011).
6. Shannon Cuykendall, Ethan Soutar-Rau, Karen Cochrane, Jacob Freiberg, and Thecla Schiphorst. 2015. Simply Spinning: Extending Current Design Frameworks for Kinesthetic Empathy. In *Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '15)*. ACM, Stanford, CA, USA, 305–312. DOI: http://dx.doi.org/10.1145/2677199.2680567
7. Marco Donnarumma, Baptiste Caramiaux, and Atau Tanaka. 2013. Muscular Interactions. Combining EMG and MMG sensing for musical practice. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME'13)*. Graduate School of Culture Technology, KAIST, Daejeon, Republic of Korea, 128–131.
8. Paul Dourish. 2004. *Where the action is: the foundations of embodied interaction*. The MIT Press.
9. Sarah Fdili Alaoui, Thecla Schiphorst, Shannon Cuykendall, Kristin Carlson, Karen Studd, and Karen Bradley. 2015. Strategies for Embodied Design: The Value and Challenges of Observing Movement. In *Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (C&C '15)*. ACM, Glasgow, Scotland, UK, 121–130. DOI: http://dx.doi.org/10.1145/2757226.2757238
10. Frank Feltham, Lian Loke, Elise van den Hoven, Jeffrey Hannam, and Bert Bongers. 2014. 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, Munich, Germany, 105–112. DOI: http://dx.doi.org/10.1145/2540930.2540974
11. Maiken Hillerup Fogtmann, Jonas Fritsch, and Karen Johanne Kortbek. 2008. Kinesthetic Interaction: Revealing the Bodily Potential in Interaction Design. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction (OZCHI '08)*. ACM, Cairns, Australia, 89–96. DOI: http://dx.doi.org/10.1145/1517744.1517770
12. Jules Françoise, Sarah Fdili Alaoui, Thecla Schiphorst, and Frédéric Bevilacqua. 2014a. Vocalizing Dance Movement for Interactive Sonification of Laban Effort Factors. In *Proceedings of the 2014 Conference on Designing Interactive Systems (DIS '14)*. ACM, Vancouver, Canada, 1079–1082. DOI: http://dx.doi.org/10.1145/2598510.2598582
13. Jules Françoise, Norbert Schnell, Riccardo Borghesi, and Frédéric Bevilacqua. 2014b. Probabilistic Models for Designing Motion and Sound Relationships. In *Proceedings of the 2014 International Conference on New Interfaces for Musical Expression (NIME'14)*. London, UK, 287–292. http://julesfrancoise.com/blog/wp-content/uploads/2014/06/Fran
14. Karmen Franinović and Stefania Serafin. 2013. *Sonic Interaction Design*. MIT Press.
15. Hubert Godard. 1995. Le geste et sa perception. In *La danse au XXème siècle*, Marcelle Michel and Isabelle Ginot (Eds.). Bordas, Paris, France, 224–229.
16. Lan-yuen Guo, Chao-pin Yang, Yu-lin You, Shen-kai Chen, Chich-haung Yang, Yi-you Hou, and Wen-lan Wu. 2014. Underlying mechanisms of Tai-Chi-Chuan training for improving balance ability in the elders. *Chinese Journal of Integrative Medicine* 20, 6 (jun 2014), 409–415. DOI: http://dx.doi.org/10.1007/s11655-013-1533-4
17. Steve Harrison, Deborah Tatar, and Phoebe Sengers. 2007. The three paradigms of HCI. In *Alt. Chi. Session at the SIGCHI Conference on Human Factors in Computing Systems (CHI EA'07)*. ACM, San Jose, CA, USA, 1–18.
18. David Hofmann. 2013. *Myoelectric Signal Processing for Prosthesis Control*. PhD Dissertation. University of Gottingen.
19. Trevor Hogan, Uta Hinrichs, and Eva Hornecker. 2016. The Elicitation Interview Technique: Capturing People's Experiences of Data Representations. *IEEE Transactions on Visualization and Computer Graphics* 22, 12 (dec 2016), 2579–2593. DOI: http://dx.doi.org/10.1109/TVCG.2015.2511718

20. Kristina Höök, Martin P Jonsson, Anna Sthl, and Johanna Mercurio. 2016. Somaesthetic Appreciation Design. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, San Jose, CA, USA, 3131–3142. DOI: http://dx.doi.org/10.1145/2858036.2858583

21. Caroline Hummels, Kees C. J. Overbeeke, and Sietske Klooster. 2007. Move to get moved: a search for methods, tools and knowledge to design for expressive and rich movement-based interaction. *Personal and Ubiquitous Computing* 11, 8 (oct 2007), 677–690. DOI: http://dx.doi.org/10.1007/s00779-006-0135-y

22. Alexander Refsum Jensenius, Kari Anne Vadstensvik Bjerkestrand, and Victoria Johnson. 2014. How still is still? Exploring human standstill for artistic applications. *International Journal of Arts and Technology* 7, 2/3 (2014), 207. DOI: http://dx.doi.org/10.1504/IJART.2014.060943

23. S. M. Lephart, D. M. Pincivero, J. L. Giraido, and F. H. Fu. 1997. The Role of Proprioception in the Management and Rehabilitation of Athletic Injuries. *The American Journal of Sports Medicine* 25, 1 (jan 1997), 130–137. DOI:http://dx.doi.org/10.1177/036354659702500126

24. Aaron M Levisohn. 2007. The Body As a Medium: Reassessing the Role of Kinesthetic Awareness in Interactive Applications. In *Proceedings of the 15th ACM International Conference on Multimedia (MM '07)*. ACM, Augsburg, Bavaria, Germany, 485–488. DOI: http://dx.doi.org/10.1145/1291233.1291352

25. Lian Loke and Toni Robertson. 2013. Moving and making strange. *ACM Transactions on Computer-Human Interaction* 20, 1 (mar 2013), 1–25. DOI: http://dx.doi.org/10.1145/2442106.2442113

26. Pedro Lopes, Alexandra Ion, Willi Mueller, Daniel Hoffmann, Patrik Jonell, and Patrick Baudisch. 2015. Proprioceptive Interaction. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 939–948. DOI: http://dx.doi.org/10.1145/2702123.2702461

27. Elena Márquez Segura, Laia Turmo Vidal, Asreen Rostami, and Annika Waern. 2016. Embodied Sketching. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, San Jose, CA, USA, 6014–6027. DOI: http://dx.doi.org/10.1145/2858036.2858486

28. John McCarthy and Peter Wright. 2007. *Technology As Experience*. The MIT Press.

29. Eduardo R. Miranda and Marcelo M. Wanderley. 2006. *New digital musical instruments: control and interaction beyond the keyboard*. AR Editions, Inc.

30. Jin Moen. 2007. From hand-held to body-worn. In *Proceedings of the 1st international conference on Tangible and embedded interaction (TEI '07)*. ACM, Baton Rouge, LA, USA, 251. DOI: http://dx.doi.org/10.1145/1226969.1227021

31. Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical Design in HCI Research: Designing and Learning Through Use-it-yourself. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. ACM, Newcastle, UK, 514–523. DOI: http://dx.doi.org/10.1145/2317956.2318034

32. Kristian Nymoen, Mari Romarheim Haugen, and Alexander Refsum Jensenius. 2015. MuMYO - Evaluating and Exploring the MYO Armband for Musical Interaction. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Edgar Berdahl and Jesse Allison (Eds.). Louisiana State University, Baton Rouge, LA, USA, 215–218.

33. Steve Paxton. 1997. Transcription. The small dance, the stand. In *Contact Quarterly's contact improvisation sourcebook*, Lisa Nelson and Nancy Stark Smith (Eds.). Vol. 1. Contact Editions, Northampton, MA, 107–109.

34. Steve Paxton. 2008. Material for the spine: A movement study. (2008).

35. Olivier Perrotin and Christophe D'Alessandro. 2013. Adaptive mapping for improved pitch accuracy on touch user interfaces. In *Proceedings of the International Conference on New Interfaces for Musical Expression*, Vol. 91403. 186–189.

36. Marianne Graves Petersen, Ole Sejer Iversen, Peter Gall Krogh, and Martin Ludvigsen. 2004. Aesthetic Interaction: A Pragmatist's Aesthetics of Interactive Systems. In *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques (DIS '04)*. ACM, Cambridge, MA, USA, 269–276. DOI: http://dx.doi.org/10.1145/1013115.1013153

37. Claire Petitmengin. 2006. Describing one's subjective experience in the second person: An interview method for the science of consciousness. *Phenomenology and the Cognitive Sciences* 5, 3-4 (dec 2006), 229–269. DOI: http://dx.doi.org/10.1007/s11097-006-9022-2

38. U. Proske and S. C. Gandevia. 2012. The Proprioceptive Senses: Their Roles in Signaling Body Shape, Body Position and Movement, and Muscle Force. *Physiological Reviews* 92, 4 (oct 2012), 1651–1697. DOI: http://dx.doi.org/10.1152/physrev.00048.2011

39. Davide Rocchesso, Stefania Serafin, Frauke Behrendt, Nicola Bernardini, Roberto Bresin, Gerhard Eckel, Karmen Franinovic, Thomas Hermann, Sandra Pauletto, Patrick Susini, and Yon Visell. 2008. Sonic interaction design: sound, information and experience. In *CHI '08 Extended Abstracts on Human Factors in Computing Systems (CHI EA '08)*. ACM, Florence, Italy, 3969–3972. DOI:http://dx.doi.org/10.1145/1358628.1358969

40. Thecla Schiphorst. 2009. soft(n). In *Proceedings of the 27th international conference extended abstracts on Human factors in computing systems (CHI EA '09)*. ACM, Boston, MA, USA, 2427. DOI: http://dx.doi.org/10.1145/1520340.1520345

41. 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, Vancouver, BC, Canada, 145–160. DOI: http://dx.doi.org/10.1145/1979742.1979640

42. Norbert Schnell, Axel Röbel, Diemo Schwarz, Geoffroy Peeters, and Riccardo Borghesi. 2009. Mubu & friends - assembling tools for content based real-time interactive audio processing in max/msp. In *Proceedings of International Computer Music Conference*. Montreal.

43. Diemo Schwarz. 2007. Corpus-based concatenative synthesis. *Signal Processing Magazine, IEEE* 24, 2 (2007), 92–104.

44. Richard Shusterman. 2012. *Thinking through the body: Essays in somaesthetics*. Cambridge University Press.

45. Atau Tanaka and Benjamin Knapp. 2002. Multimodal Interaction in Music Using the Electromyogram and Relative Position Sensing. In *Proceedings of the International Conference on New Interfaces for Musical Expression (NIME'02)*. Dublin, Ireland, 171–176.

46. Pierre Vermersch. 1996. L'explicitation de l'action. *Cahiers de linguistique sociale* 3 (1996), 113–120.

47. Y. Visell, F. Fontana, B.L. Giordano, R. Nordahl, S. Serafin, and R. Bresin. 2009. Sound design and perception in walking interactions. *International Journal of Human-Computer Studies* 67, 11 (2009), 947–959. DOI: http://dx.doi.org/10.1016/j.ijhcs.2009.07.007

48. Danielle Wilde, Thecla Schiphorst, and Sietske Klooster. 2011. Move to Design/Design to Move: A Conversation About Designing for the Body. *ACM Interactions* 18, 4 (jul 2011), 22–27. DOI: http://dx.doi.org/10.1145/1978822.1978828

49. Ann Woodhull. 1997. The small dance, physiology and improvisation. In *Contact Quarterly's contact improvisation sourcebook*, Lisa Nelson and Nancy Stark Smith (Eds.). Vol. 1. Contact Editions, Northampton, MA, 24–26.

50. Peter Wright, Jayne Wallace, and John McCarthy. 2008. Aesthetics and Experience-centered Design. *ACM Transactions on Computer-Human Interaction* 15, 4 (dec 2008), 1–21. DOI: http://dx.doi.org/10.1145/1460355.1460360

51. 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)*. ACM, San Jose, CA, USA, 493–502. DOI: http://dx.doi.org/10.1145/1240624.1240704