Movits: a Minimalist Toolkit for Embodied Sketching

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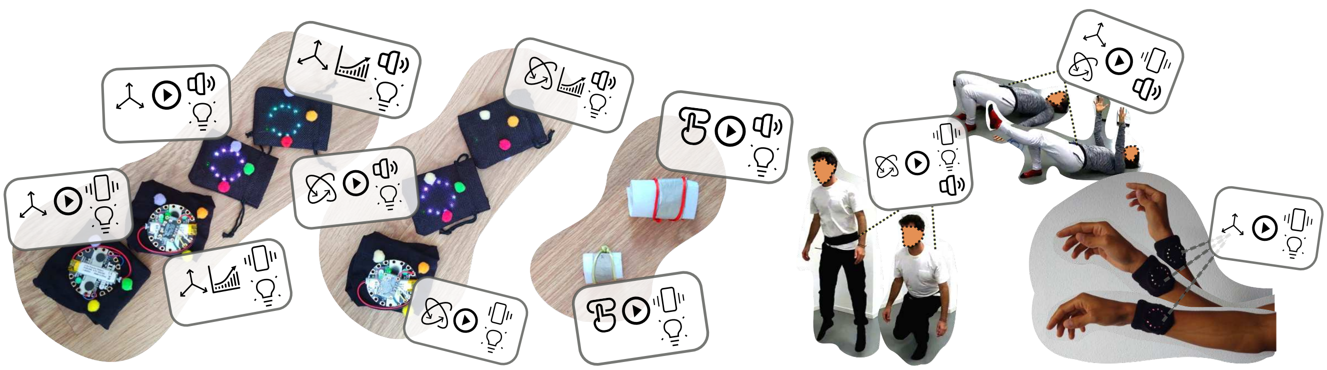

Figure 1: The Movits, the icons that represent their interactions and designs that were ideated during the evaluation workshops.

ABSTRACT

We present the design and evaluation of the Movits, a minimalist toolkit for embodied sketching design explorations. The toolkit includes technology probes featuring minimalist wearable digital units that support the hands-on exploration and design of movement-driven interactions using multisensory feedback. The Movits are self-contained and generate audiovisual or vibrotactile patterns in response to movement-based inputs. We present the theoretical and empirical grounding driving our design process. We discuss the findings of using the Movits during four co-design workshops with design students, technologists, dancers and physiotherapists, where they resulted in being generative and adaptable to a range of embodied design approaches. We contend that the Movits can be favourable for those interested in a holistic design approach to wearables in general and specifically for those targeting movement-based application domains.

CCS CONCEPTS

• **Human-centered computing** → **Systems and tools for interaction design**; **User interface toolkits**.

KEYWORDS

Wearables, Toolkit, Technology Probes, Embodied Sketching, Motor Learning, Multisensory Feedback, Biofeedback, Ideation, Bodystorming, Bodystorming Basket, Ideation Props, Ideation Probes

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1 INTRODUCTION

The design community has long realised the importance of taking an embodied and holistic approach to design. To help in this regard, they have developed strategies, such as design methodologies like Embodied Sketching [28] and Soma Design [12, 13]; and custom design tools. Among the latter, we find bodystorming baskets [54] as collections of simple and diverse props for ideation. While often these props are analogue—such as balls, textiles, play jewellery, styrofoam objects, and mechanical gadgets—, they might also include simple off-the-shelf technology like a buzzer or a laser pointer, featuring simple interactivity relevant for the application domain [49, 54]. These technological props can be evocative and may help spur creativity, allowing participants to engage multisensorially and explore design possibilities. However, depending on the design challenge, it might be hard to find a diverse set of proper interactive props with befitting propertiesto the target application domain, which may affect ideation.

In such situations, it is worth considering having a bodystorming basket with ad hoc technology props or probes [11]—simple, flexible and adaptable technologies to inspire users and researchers to ideate new technologies [11]. Many examples can be found in the design research community. Several of these toolkits assemble a collection of *Bits*—the Inspirational Bits [39], the Soma Bits [56, 57], the Menarche Bits [40, 41], the Wearable Bits [15] and the DanceBits [5].

This paper adds to this body of work focusing in particular on the domain of *movement-based design*. Designing for the moving body—design target—with the moving body—design approach—presents unique challenges and requirements for ideation tools that need to be considered. For instance, it is important that the designed feedback does not interfere with the movement practice [48]. In this domain, however, there are fewer examples of toolkits or bodystorming baskets. One such example is the Training Technology Probes (TTPs) [25, 26, 47]—simple wearable devices that take key body parameters as input, such as movement speed and body orientation, and provide multisensory feedback.

Our work is situated in the context of a larger research project focused on co-designing playful wearable technology for movement learning in rehabilitation and physical training. As part of this project, we were interested in designing and employing a toolkit of probes that would serve as an aid for our participatory embodied sketching workshops. The toolkit would enable the relevant stakeholders in our project—interaction designers, engineers, movement and health professionals in the areas of rehabilitation, physical therapy and occupational therapy, along with their patients—to establish common ground regarding the possibilities of interactive technologies that provide multisensory feedback and empower them all to contribute to the design process.

In the paper, we report on the design, development and evaluation of the Movits[1], a toolkit of minimalist technology probes that support hands-on explorations and design of future interactions driven by movement and multisensory feedback (Fig. 1). The Movits are relatively small and simple wearable digital units that provide audiovisual or visuotactile patterns in response to body inputs such as motion, spatial orientation or touch. The design of our toolkit is driven by key design qualities and requirements connected to our application domain. In particular, we sought our toolkit to be modular, interactive, open-ended, simple, easy to deploy and with a strong focus on movement-based applications. While some of these characteristics are present in previous works, none of them feature all of them in the form of an ideation toolkit.

In the paper, we detail the analysis leading our design process, describe the resulting toolkit, and discuss four evaluation workshops with different participants—design students, technologists, dancers and physiotherapists—, and the insights they yielded. In previous work [53], we described the toolkit and provided an overview of our design process. Here, we expand on the design process, evaluate and analyse a series of workshops featuring the toolkit, and discuss emerging results and insights.

The Movits emerged from the specific context of motor learning and training. Hence they can be most useful for those interested in an embodied and holistic design approach to designing wearables in motor learning application domains. However, both the design process and the resulting toolkit modules reflect, simplify, and generalise proven interactions in previous works on wearables for diverse movement practices and embodied design toolkits. This conceivably makes the Movits generative and adaptable in diverse movement practices and movement-centred application domains to design movement-based technology in general and wearables in particular. Additionally, we designed them so that others can replicate and use them. Further, the Movits can complement and be used with other assorted non-digital objects during embodied sketching sessions. Finally, the findings of our evaluation workshops extend prior knowledge and can be applicable for future research and design of toolkits, probes, and technologies that consider an embodied and holistic approach [12, 28] in their interactions.

[1]Portmanteau word from both *Move(ment) Bits* and *Move-its*

2 RELATED TOOLKITS AND DESIGN INSPIRATION

2.1 Toolkits and Probes for Embodied Interaction Design

Movement-based design research often explores, produces and employs toolkits and probes to facilitate design sensitisation, exploration and ideation [54]. Some of these toolkits and probes inform and inspire our work. For instance, from the Embodied Ideation Toolkit [10, 36] we draw inspiration regarding the curation, design and use of multiple tangible objects to support embodied co-design processes with the participation of diverse stakeholders. In our work, this is related to the concept of *technology probes*: simple, flexible and adaptable technologies designed to inspire users and researchers to ideate new technologies [11]. Furthermore, we are influenced by the Inspirational bits [39], which developed multiple units that exposed the workings of common technologies and input modalities. Relatedly, research in embodied interaction domains has suggested a *bodystorming basket* [54], a toolset for embodied design ideation methods, such as Bodystorming for movement-based interaction design [27] or Sensory Bodystorming [49].

Similarly, our work draws from toolkits and probes often employed in Soma Design [12, 13] processes, such as the Soma Bits [56, 57]. Soma Bits were introduced as a kit of objects that allow exploring haptic modalities—vibration, heat, and inflatables—at varied levels of intensity and in different parts of the body [56, 57]. The kit combines the Soma Bits—the devices consisting of electronic actuators, control units, knobs and power—with the Soma Shapes—soft and diverse objects with pockets to place the Bits [56, 57]. Related to the Soma Bits, but not developed as a toolkit *per se*, the Felt Sense Glove [29, 30] and Sense Pouch [30] were ideation probes that supported exploration of the effects of heat and vibration in people's somatic experiences. In a similar line, but intended as an open-ended prototyping toolkit to design wearable menstrual technologies for young adolescents, the Menarche Bits [40, 41] consisted of custom shape-changing actuators and heat pads.

Another line of research into toolkits concerns designing individual modules that can be interconnected and used to explore and prototype wearables and e-textiles. For example, the Wearable Bits [15] were a modular set of patches of different levels of fidelity with common electronic components—sensors and actuators—that could be arranged according to one's design and prototype. Focusing on haptic feedback, the TactorBots [62] consisted of a toolkit of multiple wearable units where each one provided a different type of touch gesture. The touch gestures implemented in these units arose from an analysis of prior work, similar to the process we follow in this paper. The design process of the TactorBots resulted in a comprehensive toolkit which could render all touch types, could be worn in any place of the body, and could be used in the wild [62]. The Kit-of-No-Parts approach [32] consists of handcrafting textile interfaces—such as tilt, pressure or stroke sensors—from scratch so that one can personalize, understand and share them. Furthermore, the DanceBits were developed as a wearable prototyping kit for dance that was co-developed with a justice-oriented, computing and dance education organization [5]. The DanceBits provided several input components, such as buttons and tilt sensors, and output components, such as different types of lights, that could be easily interconnected to design and perform choreographies while wearing electronic costumes [5]. We take inspiration from all these kits in how they identified and built minimal modules with a single function each.

More directly related to our work are the Training Technology Probes (TTPs) [25, 26, 47]. These were a collection of simple wearable devices that sensed a few body parameters, such as movement speed, body orientation or breathing, and provided feedback loops through different sensory modalities—e.g. lights, sound and vibration mapped to orientation or motion [25, 26, 47]. They emerged from diverse embodied sketching activities [28, 49]. While they were not specifically designed as an ideation toolkit themselves, they lent themselves to be appropriated, iterated, and re-designed to be used in diverse contexts related to motor learning and training. For instance, the TTPs have been used in a multitude of projects relating to motor learning in circus training, yoga, weightlifting and physical training in general [25, 26, 45–47, 51]. This was due to key properties of the TTPs, such as their simplicity, open-ended feedback and use of redundant multisensory feedback for the wearer and others, all of which we take as inspiration for our toolkit.

Our work draws inspiration from these prior toolkits and probes in different ways. We share with the Soma Bits [56, 57], Menarche Bits [40, 41], Wearable Bits [15] and TTPs [25, 26, 47] the values of minimalism and the holistic understanding of embodied experiences, where technology is not the sole focus. The insights from studies with the TTPs [25, 26, 47] comprised the empirical grounding of the Intercorporeal Biofeedback strong concept [48], which we used as an analytical lens in our work. We took from the Embodied Ideation Toolkit [10, 36] and the description of bodystorming baskets [54] the approach of bringing a variety of small, readily available probes to help stakeholders engage in embodied design activities. Finally, we share with the Wearable Bits [15], Soma Bits [56, 57], TactorBots [62], Kit-of-No-Parts [32] and DanceBits [5] a design approach based on individual modules with identifiable functions. Additionally, we have in common with all these projects the provision of open-ended modules that can be adapted to different situations.

2.2 Inspirations for Designing our Toolkit

We present approaches, concepts, exemplars and general knowledge areas that have inspired and grounded the creation of the toolkit.

2.2.1 Methodological Approaches. To develop the toolkit, we drew inspiration from Soma Design approaches [12, 13] in designing tools to deepen people's sensory appreciation of their bodies or the bodies of others. We focused on designing the Movits so that they could be experienced in an intimate correspondence [13], that is, in tight and intimate feedback loops that could be experienced as a reflection, or mirror, of the body. These approaches are present as well in some of the aforementioned probes and toolkits: the Soma Bits [56, 57], the Menarche Bits [40, 41], and the Felt Sense Glove and Sense Pouch [29, 30].

We also drew inspiration from Embodied Sketching [28], a collection of methods that involve exploring, understanding and designing embodied experiences, physically and playfully, employing and focusing on their key embodied core mechanics [23]. Embodied Sketching is done early in the design process with different stakeholders [28]. To assist embodied sketching design activities [24, 28], we designed a toolkit that could be easily deployed in such physical, hands-on, playful and movement-based design processes [54] by prioritising simplicity of use and ubiquitous wearability.

2.2.2 Theoretical Concepts. Our work is directly influenced by the strong concept [14] of Intercorporeal biofeedback [48], which proposes the role of interactive technology as a mediator that can support joint sensemaking on body processes by different actors [48]. Articulated through design work focused on practices of movement teaching and learning, the concept presents a way to design biofeedback technology to achieve such a role. It proposes four core characteristics that we have directly implemented in the design of the Movits. An intercorporeal biofeedback tool should, first, provide a *shared frame of reference* so that the biofeedback is accessible—through using e.g. audiovisual or visuotactile and not only vibrotactile feedback—to different people at the same time. This helps create a frame that involved parties can refer to in their sensemaking processes. Secondly, such a tool should support a *fluid meaning allocation*, i.e. supporting in-the-moment constructive meaning-making by people by favouring open-endedness [51] in the feedback representations. Thirdly, it should support *guiding attention and action*, enabling a focus of attention fluctuation from the body to the biofeedback, their tight loops, or the instructions provided by observing peers [48]. Finally, it should be designed as an *interwoven* *interactional resource* to be used alongside a wider variety of interactional resources—such as verbal instructions, demonstrations, and material equipment [48]—, so that the technology does not become the sole focus of the interaction.

Theoretically, Intercorporeal Biofeedback builds on movement science concepts that are also relevant to the design of the Movits, in particular, the use of an *external focus of attention* to support movement learning. The focus of attention refers to the location to which a person pays attention while performing a certain movement [20]. An external focus of attention consists of directing the learner's focus to the effects of their movements on the environment, such as to an apparatus or implement [60]. In contrast, an internal focus of attention consists of concentrating on the inside of the body while performing a movement [20]. Existing studies on attentional focus have generally recognised the benefits of adopting an external focus over an internal focus in motor learning and performance in a variety of practices such as golf [16], tennis [59], standing long jump [58], swimming [38], jump height [1], throwing [61], and striking combat sports [7]. The Movits foster an external focus of attention through their use of multisensory feedback—audiovisual or visuotactile—in response to their wearer's movements.

2.2.3 Multisensory Technologies for Movement Learning. Finally, we also drew inspiration from existing wearable exemplars which employ multisensory technologies in movement learning or physical activity contexts, such as sports, rehabilitation, and fitness. For that, we used the works featured in the recent literature reviews of Mencarini et al. [22], Turmo Vidal et al. [48, 52] who analysed wearables for such contexts. The reviewed projects included technologies for augmented and multisensory feedback in circus—*LISTO* and *TRAP* [34], *SonicHoop* [19], and *TTPs* [25, 26, 47, 51]; weightlifting—*GymSoles* [6]; winter sports—*Augmented Speed-skate Experience* [37] and *Motion Echo Snowboard* [31]; yoga—*TTPs* [25, 44, 47]; or physiotherapy for chronic pain—*Go-with-the-Flow* [35]; technologies for transformation of body perceptions to support physical activity—*Soniband* [17, 18, 42], *Sonishoes* [42, 43] and *Vibratory patterns* [42]; and technologies for, or resulting from, soma design explorations—*Sounds of Synchronous Movements* [2], *Felt Sense Glove* [29, 30] and *Sense Pouch* [30]. In Section 3.1, we discuss the findings we gathered from our review. Furthermore, we used the same review works [22, 48, 52] to support the classification of designs in our evaluation workshops (Fig. 6) discussed in Section 5.

3 DESIGNING THE MOVITS

The Movits emerged in the context of a larger research project that aims to co-design playful wearable technology for movement learning in contexts of rehabilitation and physical training, specifically for supporting physical training in flexibility and strength using multisensory feedback. To design them, we were interested in analysing the features of previous projects of wearables for movement learning and physical activity and prior work in toolkits for embodied interaction design—both areas discussed above in Section 2—so that we could develop minimalist versions of common interactions they presented. We were especially curious about the modalities of inputs and outputs they had, as well as the type of mappings between them they conveyed (Sec. 3.1). To guide us during the design process, we established a list of design requirements based both on personal values we wanted to put forward and on the theoretical concepts and methodological approaches that inform our work (Sec. 3.2). These requirements and the results of our analysis, in combination, supported us in selecting the hardware and software platforms we would use (Sec. 3.3), and in delimiting the types of interactions we would like to develop as a first iteration of the kit (Sec. 3.4).

3.1 Inputs, Outputs and Mappings

We analysed the modalities of *inputs* and *outputs* employed in the related toolkits and probes (Sec. 2.1) and related projects of wearables and multisensory technologies in movement learning or physical activity contexts (Sec. 2.2.3) from our review, extending the previous one in Vega-Cebrián et al. [53]. In terms of input modalities, we found that projects used spatial orientation [2, 5, 17, 18, 25, 26, 35, 42, 42, 42–44, 47], motion [17, 18, 25, 26, 34, 37, 42, 43, 47], pressure [6, 26, 31, 34, 37, 42, 43], touch [19, 29, 30], buttons [5], knobs [56, 57], biosignals [2] and fully-fledged graphical user interfaces [62]. Regarding output modalities, we found the use of sound [2, 17–19, 25, 26, 35, 37, 42, 43, 47], vibrotactile haptics [6, 25, 26, 29, 30, 42, 47], lights [25, 26, 31, 34, 44, 47], shape-changes through inflation [40, 41, 56, 57], heat [30, 56, 57] and robotic touch gestures [62] as outputs. Figure 2 illustrates the inputs and outputs we found and the relationships between them.

Additionally, we noted the type of relationship that was established between inputs and outputs. Roughly, they could be classified as either continuous or discrete. A *continuous* mapping would involve the direct or inverse proportional modulation of a dimension of the output—e.g. pitch, frequency, intensity, colour—in relation to the input. A *discrete* mapping would be based on single or multiple thresholds of the input quantities that trigger a behaviour—e.g. a musical note or a vibration pulse—when crossed.

3.2 Design Requirements

Our goal with the Movits design was to generate a toolkit of *minimal* units reflecting preexisting and proven interactions in open-ended wearable projects for movement applications employing augmented feedback. Our aim was that such a toolkit could contribute to our overarching aim of fostering exploration and idea generation in movement-centric domains using interactive technology. Based on the design inspirations presented in the previous section, we articulated a series of values that we aimed to inculcate in our toolkit design. For instance, when we refer to *minimal* units, we aim to indicate simplicity—i.e. *low complexity*—and the decision to only use the technologies that would be *necessary and sufficient* [33] for the task. Towards the design of the first set of our toolkit, this would mean that the Movits should be *self-contained* and work in a standalone manner: we should be able to bring them into an embodied design workshop without having to bring an extra computer to make them work or troubleshoot them. Therefore, the devices should provide *straightforward interactions* without a setup or calibration step: one should be able to turn them on and start using them immediately. This would likely help participants to figure out meaningful interactions by organically exploring them. Additionally, the Movits should work *offline*, i.e. without Wi-Fi or other wireless communications. This would support embodied sketching

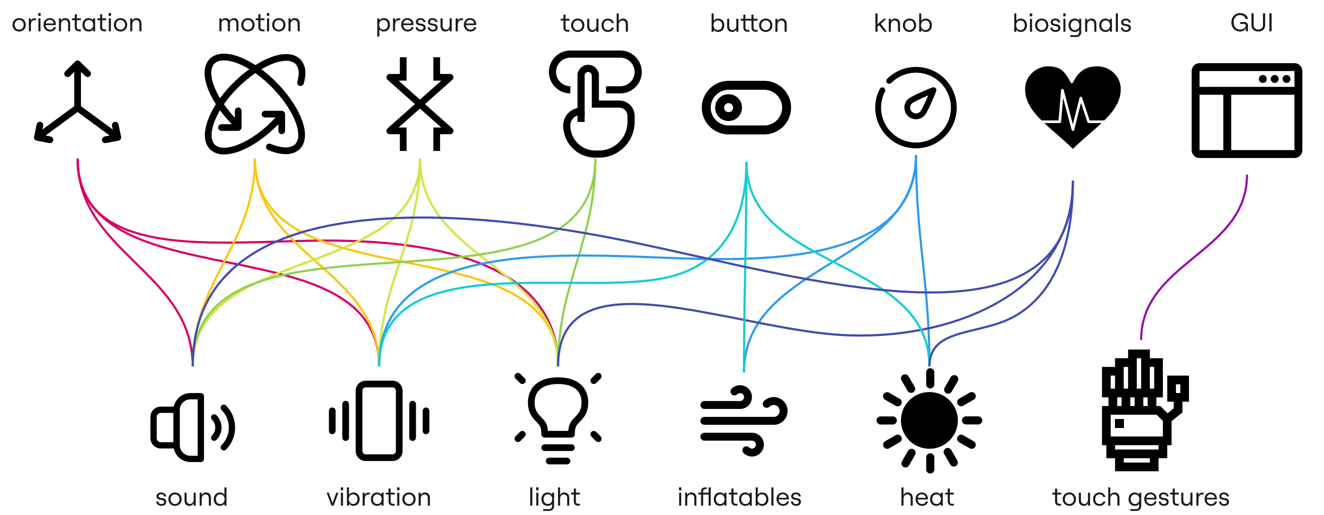

Figure 2: Inputs (top), outputs (bottom) and their connections found in our literature review. Icons provided by Iconfinder in Miro.

done in the wild or outdoors. Additionally, this would reduce technical complexity during embodied design workshops, keeping the focus on embodied action rather than on troubleshooting. We left for future work to develop relatively more complex design probes implementing features such as communication. For now, and for the early design stages that the Movits target, we are contented with such interaction between devices being able to be simulated or puppeteered in a Wizard of Oz manner [4].

Our toolkit draws on the intercorporeal biofeedback [48] strong concept using its four characteristics to shape our design goals and envisioned *preferred state* [63]: the units in the toolkit would be intended to provide a *shared frame of reference*, via audiovisual or visuotactile feedback, that thanks to their open-endedness would likely allow its users to engage in *fluid meaning allocation*. Because of the minimalism in their behaviour, they would likely be unobtrusive. Therefore, they could be used to *guide attention and action* as an additional and complementary—to other objects and activities—, *interwoven interactional resource*. Furthermore, the toolkit would reflect an Embodied Interaction approach, and be designed in particular to support embodied design methods, such as those within embodied sketching [28]: sensitizing, ideating and prototyping, in particular in the context of movement learning experiences.

3.3 Hardware and Software

We chose to develop our toolkit using Adafruit Circuit Playground Express and Gemma M0 boards, along with some extra components—vibration motors, motor controllers and buzzers. We selected these platforms because of their assortment of built-in components and capabilities—such as accelerometers, speakers, lights, buttons, and capacitive touch input—and computational specifications which allow for simple sound processing and playback of short sound samples. Additionally, we decided to use these boards because of their potential availability as prototyping tools across research and design institutions. We intended to streamline the process of researchers and designers getting up and running with our system. Furthermore, these boards reside at a middle ground regarding complexity in hardware and software, ideal for our design goals. For the physical construction of the Movits, besides the boards, we used e-textile materials such as conductive thread and fabric, soft enclosures and straps. The Movits have velcro behind them so that they can be attached to textile straps worn on arms, legs, head or torso, or directly to the wearer's clothes. For programming the Movits we chose to use CircuitPython to leverage its support for beginners and allow for a simple re-configuration of its parameters should a more advanced design session require it.

3.4 Selection of Inputs and Outputs

We chose to craft a first iteration of the toolkit implementing the more common modalities in our analysis (Sec. 3.1), which at the same time were simpler in terms of setup, implementation, and use. We were interested in having enough modalities that could still support and reflect more rounded and polished movement-based designs, such as those in the multiple projects reviewed. For this, we selected three types of inputs—*orientation*, *motion* and *touch*—, and three types of outputs—*sound*, *vibrotactile haptics* and *lights* (Fig. 3). We chose *touch* as an input because we gathered it could emulate to some extent the behaviours provided by the *pressure* and *button* inputs while being relatively simpler to implement with the tools we selected.

For the first iteration of the Movits, we decided to focus on the two most prominent output modalities in our analysis, *sound* and *vibration*. We wanted to keep them in separate modules to be able to evaluate differences in their use. We reasoned that if someone wanted to use these modalities together, they could physically join the Movits which exhibited them. However, to maintain a *shared frame of reference* [48], the vibration had to be accompanied by

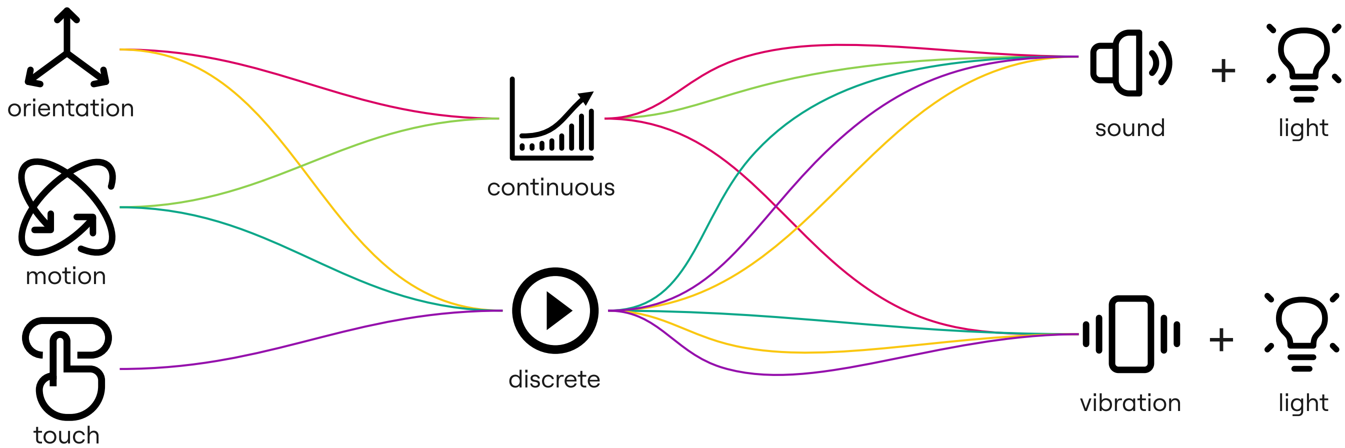

Figure 3: The inputs, mappings and outputs we selected. Icons provided by Iconfinder in Miro.

another modality perceivable from the outside, and for this, we chose lights. Vision is our primary sensory modality, and people can easily and readily make sense of visual information [49], which, when well designed, has proven to be useful in dynamic and changing contexts of movement teaching and learning [51, 52]. Further, as the use of lights synchronised with other outputs is technically straightforward with the boards we chose to use, we decided to incorporate them into the Movits with sound as an output as well. In this way, the Movits would provide either *audiovisual* or *visuotactile* feedback. Figure 3 illustrates the inputs, outputs and mapping we chose to implement in the first iteration of the Movits.

4 THE MOVITS TOOLKIT

We designed a total of nine Movits divided into three groups according to their input: four Tilt Movits that use orientation[2], three Motion Movits that use the measured change of acceleration, and two Touch Movits that use capacitive touch (Fig. 4). In the name of each Movit, we attempt to indicate their behaviour using three parts: (1) the type of input, (2) the word "To" or "Play" to indicate a continuous or discrete mapping respectively, and (3) a descriptive word indicating the type of output. Table 1 provides an overview of their names, inputs, outputs, mappings and basic interaction. [3]

The Movits provide either *audiovisual* or *visuotactile* feedback. Their bi-modal output is intended to assist the *shared frame of reference* between wearers and audience as postulated by intercorporeal biofeedback [48]. The output of each of the units was designed to be open-ended—thus likely allowing for a *fluid meaning allocation* [48] between their users—, and unobtrusive—so that it would be feasible to *guide attention and action* [48] toward and away from it, and it could potentially blend well as an *interwoven interactional resource* [48].

We included in the Movits a minimal degree of configuration, as we imagined that it could be useful to better adapt them to a specific design scenario. For instance, all of them have a switch that allows one to turn off the sound or vibration, leaving the lights only. This originated as an aid during development but became useful when demonstrating the Movits. Additionally, the Tilt and Motion Movits make use of the two buttons in the Circuit Playground Express boards. One button allows one to cycle between *modes of operation*, for instance changing the axis of rotation for the Tilt Movits, the initial pitch in MotionToPitch, the collection of sound samples in MotionPlaySample or the duration of vibration in MotionPlayVibration. The other button enables one to cycle between up to three levels of perceived *sensitivity* by changing the trigger thresholds in the case of the discrete interactions or the range of output in the continuous interactions.

To design the Movits, we were interested in attempting to convey a straightforward mapping of their input modality by activating or modulating a single parameter of the output. In line with our decision to separate the sonic and haptic feedback from the Movits, our intention for designing them consisted of abstracting and simplifying the interactions of our references—when they existed—so that each resulting Movit would exhibit a single behaviour. For more details on the individual workings of each Movit and the references they are based on, see our previous work [53]. Additionally, the source code we wrote along with installation instructions can be found in an online repository [55].

5 TESTING THE MOVITS: FOUR WORKSHOPS

To validate the potential of the Movits as ideation probes for explorations of movement-based design, we organised four embodied sketching workshops with different populations. The workshops were part of a larger project that aims to co-design and develop playful wearable technology for movement learning in contexts of rehabilitation and physical training, specifically for supporting physical training in flexibility and strength.

5.1 Workshop Participants

We were interested in probing the potential and limitations of the Movits. While the Movits were originally conceived to be used in

[2]We chose to name them Tilt Movits because they use a specific instance of *orientation*: the angle of rotation around a single axis, orthogonal to the gravity.
[3]Note that these are the same devices described by Vega-Cebrián et al. [53] but with different names—to provide better clarity of the interaction provided by each one—and configuration capabilities.

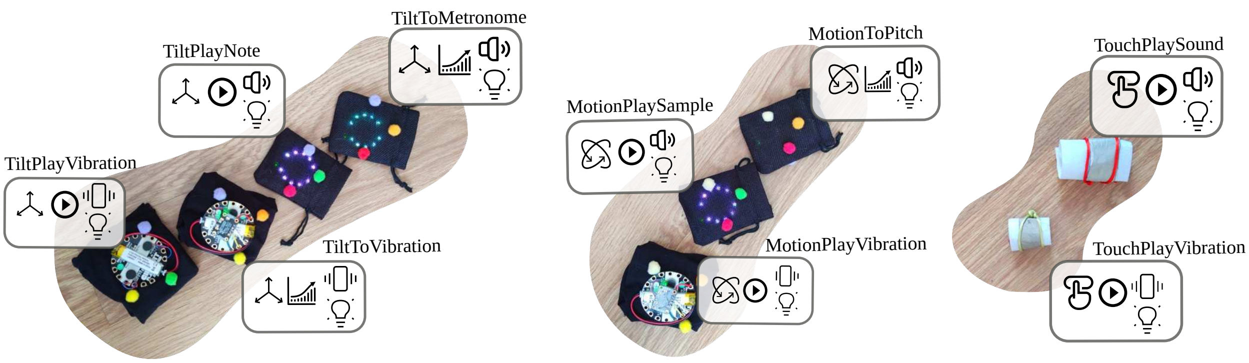

Figure 4: Overview of the Movits.

Name	Input	Output	Mapping	Interaction
TiltToMetronome	Orientation	Audiovisual	Continuous	The frequency of the metronome is proportional to the rotation angle.
TiltPlayNote	Orientation	Audiovisual	Discrete	Single musical notes are assigned to equal sections of the full rotation.
TiltToVibration	Orientation	Visuotactile	Continuous	The vibration intensity is proportional to the rotation angle.
TiltPlayVibration	Orientation	Visuotactile	Discrete	A vibration starts when crossing a threshold of rotation angle.
MotionToPitch	Motion	Audiovisual	Continuous	The pitch of emitted tones is proportional to the amount of motion.
MotionPlaySample	Motion	Audiovisual	Discrete	Sound samples are played when crossing a threshold of motion.
MotionPlayVibration	Motion	Visuotactile	Discrete	A vibration starts when crossing a threshold of motion.
TouchPlaySound	Touch	Audiovisual	Discrete	A tone is played when touched.
TouchPlayVibration	Touch	Visuotactile	Discrete	A vibration starts when touched.

Table 1: Interactions provided by the Movits.

participatory design workshops inviting professional physiotherapists, we were also interested in testing if the Movits lent themselves as useful creative tools for participants from different contexts and with different backgrounds and expertise. Hence, we organised several workshops with different participants. All of them focused on wearable design and ideation. Workshops 1 and 2 targeted a broader population of students (Workshop 1) and the general public (Workshop 2) with overlapping interests in the project—creativity and design, movement practices, and technology innovation. These workshops served as pilots for the workshop and Movits and helped us refine them for the subsequent workshops. Workshops 3 and 4 were meant to further inspect and evaluate the Movits in use by the actual target population.

In Workshop 1, we hosted 15 undergraduate students who were part of a Creativity and Design course taught by the fifth author. The class was a non-mandatory lab part of the course's usual class schedule. For Workshop 2, we had an open call for the general public in the context of a nation-wide science dissemination event. The workshop was advertised on the regional website of the event featuring multiple workshops and activities, and on the research group's website. We welcomed five participants: three of them reported having technology innovation jobs and two of them were multidisciplinary dancers. For these two workshops we did not gather demographic data for data protection reasons. For Workshop 3 and 4, the fourth author directly invited a group of professional physiotherapists from his professional network. We had four participants in Workshop 3 and three participants in Workshop 4. The mean age of the seven physiotherapists was 43.2 years (SD = 6.0) with a mean professional practice of 20.1 years (SD = 5.9). The expertise of the physiotherapists included sports, movement coaching, global postural reeducation, osteopathy, and core, perineum and pelvic floor reeducation. None of the participants in the four workshops received monetary compensation for their participation.

5.2 Workshop Structure

The four two-hour workshops shared the same objective and general structure (Fig. 5). Participants utilised the Movits as ideation probes for designing wearable technologies to support physical training in flexibility and strength. The four workshops were framed as standalone events, i.e. they were presented as the only instance of participation for the attendees without an expectation of further collaboration. In Workshops 1 and 3, participants worked in pairs or trios; in Workshop 2, they worked individually with a facilitator assisting each one, and in Workshop 4, they worked individually with a single rotating facilitator. We followed a double diamond [3] structure, adapting its four stages: Discover, Define, Develop and Deliver. We employed the Movits for bodystorming [27] during divergent phases—Discover and Develop—, and custom-made documentation sheets during convergent phases—Define and Deliver. In the fourth stage, participants presented and demonstrated their resulting ideas.

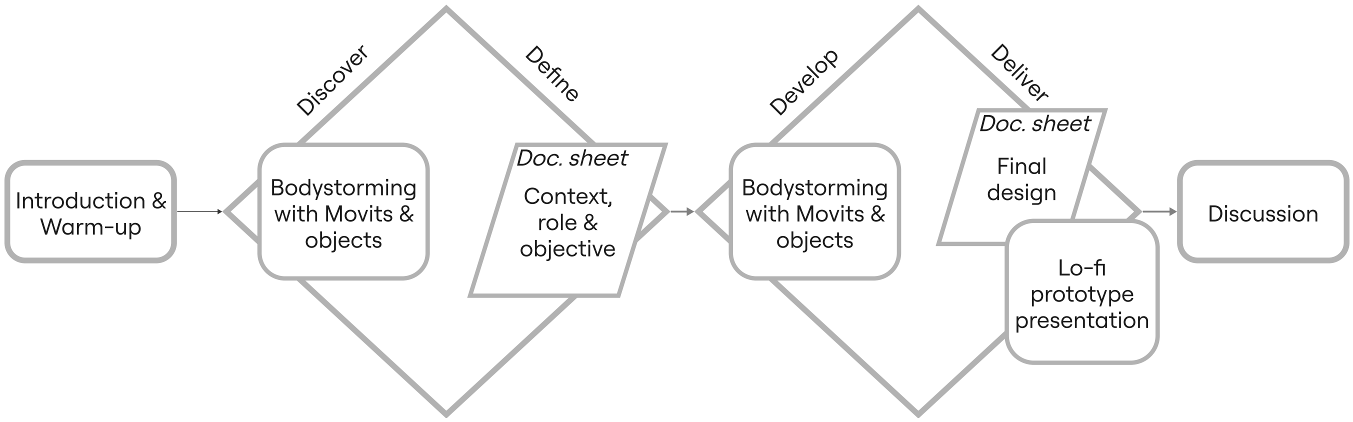

Figure 5: An overview of the structure of our workshops.

In all cases, we had a bodystorming basket consisting of fabric straps of different lengths and widths—some of them with velcro, snap buttons or plastic clasps—, pieces of fabric, cardboard, paper and EVA foam, attachment methods such as safety pins, velcro, zip ties, rope and cords, and some fabric bags with marbles or pulses to provide weight.

The workshop structure was developed by the first, third and fifth authors. The first author was the main facilitator of the four workshops, assisted in-place by one and four other researchers—including the third author—in Workshops 1 and 2 respectively. The workshops were approved by the Ethics Board of Universidad Carlos III de Madrid and all took part on university premises. In all workshops, the facilitators collected field notes and asked the participants to fill out documentation sheets of their designs. We only video-recorded Workshops 3 and 4 based on the consent provided by the participants.

All workshops began with an introduction to the research context, the workshop's general structure and the generalities of the Movits. Due to technical issues, the Touch Movits were excluded from Workshops 1 and 4. The Movits, tagged with colours and behaviour icons, were arranged on a table (Fig. 4). We did not show them in action, name them or indicate in any form which of the units would respond in which way. Then, the context of wearable design for physical training was illustrated through diagrams (Fig. 6) based on the review work of Turmo Vidal et al. [52] and Mencarini et al. [22]. The depth varied across groups: in Workshops 1 and 2 the context was provided as a general overview, whereas in Workshops 3 and 4 we further discussed the implications of these frameworks to design wearable technologies for movement learning. A brief warm-up activity was conducted to motivate a creative focus; it followed a sequence of (1) a body scan meditation, (2) a visualization activity, (3) a movement-based game where people introduced themselves by synchronizing their names with a chosen movement, and (4) a somatic activity to explore different ranges of motion. In Workshop 1, the warm-up consisted of remembering and visualising these activities, which had been performed in a previous session.

5.2.1 Discover. For the initial divergent phase, participants silently explored Movits for five minutes. Their objective was to choose two—per group or person, depending on the workshop—for the session and to arrive at an initial understanding of their behaviour. After selecting their Movits, the participants explained their findings to the group, with facilitators offering clarification. For example, it could happen that they understood a continuous behaviour as discrete because they did not explore the middle steps of the input range, or that they thought that a Movit was responding to tilting when it was responding to motion, or vice versa.

Then, we facilitated a bodystorming [27] activity to explore possible applications in the context of wearable technologies for physical training. We defined three exploration phases to loosely guide participants in their explorations: (1) Movit placement on their bodies—using straps and other mechanical aids from the bodystorming basket—; (2) movement range levels; and (3) diversity of actions in sports and fitness practices. In practice, the flow of ideas was so rich in covering these dimensions and more that we did not need to indicate separate phases. This divergent activity lasted approximately 15 minutes.

5.2.2 Define. After guiding participants back to a seated position, we introduced the first documentation sheet for the first convergence step. Participants were asked to define the context for the wearable technology they would like to design, based on their findings during the previous phase. Then, using a diagram from the design space of wearables for sports and fitness practices [52], we prompted them to consider roles for the technology outputs: to support some *experiential quality* or to *convey information* through *augmented feedback*—be it knowledge of the current performance or knowledge of results—or *feed-forward*—providing information in advance (Fig. 6.a). We told them that these roles were non-exclusive. Finally, we asked participants to consider the objective of their technology—to enable, improve or augment—across physical, cognitive, emotional and social aspects of the context they chose, using a diagram based on the review of trends and opportunities of wearable systems for sports by Mencarini et al. [22] (Fig. 6.b). Again, we clarified that these objectives were non-exclusive. The facilitators

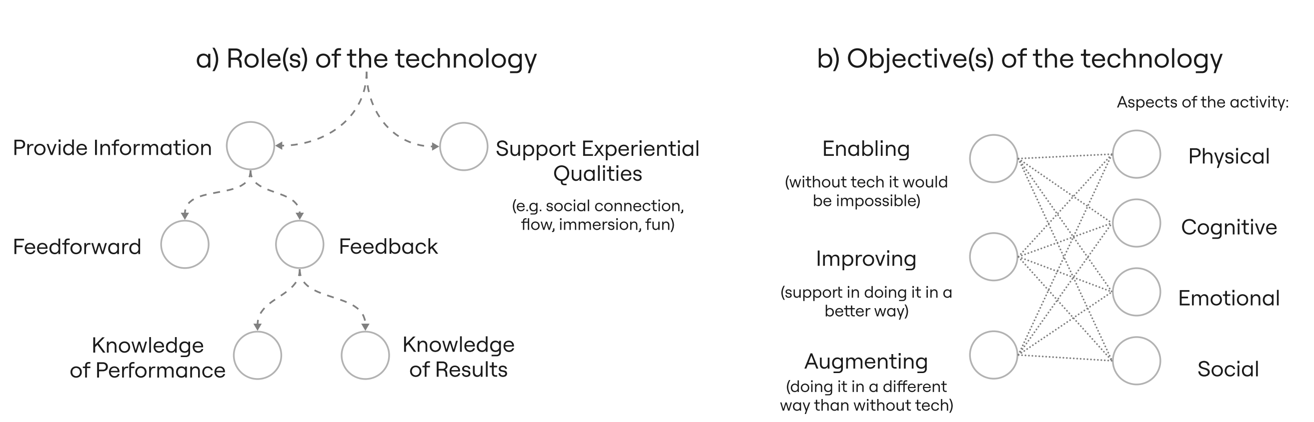

Figure 6: Diagrams used in our first documentation sheet: a) Roles of the technology, based on Turmo Vidal et al. [52], b) Objectives of the technology, based on Mencarini et al. [21]

adapted to participants' needs by answering questions or assisting with idea framing. This activity lasted approximately 10 minutes.

5.2.3 Develop. For the second round of convergence, participants engaged in another 15-minute bodystorming [27] activity to develop a concrete idea within their chosen context. We prompted the exploration of Movit placements and consideration of design aspects like shape, texture, weight, feedback types, configuration modes and compatible movements. Facilitators adapted prompts to each group or individual based on the participants' process. For instance, in Workshops 3 and 4, physiotherapists had very clear ideas of possible applications, so we guided them towards a detailed specification of what they envisioned. In contrast, in Workshops 1 and 2, our work as facilitators consisted of guiding participants towards deciding on a single idea and developing it. In all cases, we encouraged participants to use the available objects from the bodystorming basket in combination with the Movits to build a low-fidelity prototype, extending or discarding the actual behaviour of the Movits that they had chosen as inspiration.

To keep the activity manageable, with a focus on embodiment and not on technicalities, we did not initially communicate the configuration capabilities of the Movits, except when the participants: (1) accidentally pressed buttons, leading to notable changes in what they were exploring—e.g., the responsiveness of a Motion Movit was now too much or too little for their chosen movement, or a Tilt Movit was not responding the same way to the movement they had tried before—; (2) voiced a very specific need that could be met by this configuration change, such as a sensitivity adjustments in the Motion Movits or axis changes in the Tilt Movits.

5.2.4 Deliver. For the second convergent stage, participants completed two tasks with a 10-minute time limit. First, we provided another documentation sheet for specific details of their final design, including a general description, an account of the concrete application, behaviour and expected results of the technology, and a body map to illustrate the shape and placement of the design. Additionally, we asked participants to reflect on the features of the Movits they used in or left out of their design, the changes they made and the helpfulness of the toolkit in their design process. To conclude, participants presented a low-fidelity prototype of their design (Fig. 7) and engaged in a Q&A session with the facilitators and the rest of the participants.

The workshop ended with a semi-structured group discussion exploring overall experiences, feelings and insights from both divergent and convergent phases—taking into account the differences between the movement-based nature of the former and the written and analytical aspects of the latter. Participants shared experiences through the lenses of embodied ideation methods, the use of the Movits and other objects, and teamwork.

5.3 Analysis

The analysis mainly focused on the resulting designs and on the documentation sheets filled by the participants in the workshops, which were complemented by the field notes gathered by the workshops' facilitators. For this, the first author digitised the data gathered from the documentation sheets described in Sections 5.2.2 and 5.2.4. A top-down qualitative analysis of this material was conducted, using the categories of the sheets as guiding analytical lenses, which were developed and iterated by the first, second, third, and fifth authors over the course of these and previous workshops; and appropriated by them for the reported workshops. These categories included: the application of the design, its placement in the body, the Movits in use during the workshop, the variations in the design (from the original behaviour exhibited by the Movits), the self-classification of their design regarding roles and objectives (Fig. 6), the suggested modifications to the Movits, and the reflections on their usefulness.

After this, the first author used the field notes to complement the data, as some relevant comments from the participants were not captured in their documentation sheets. The origin of each design was kept in the dataset, i.e. the authors were always aware of the workshop each idea came from.

The first author then identified emerging themes across each category roughly based on what they found more common, less common, or more relevant to the design requirements of the Movits (Sec. 3.2). These were important aspects of the overarching project and were discussed by the first, and fifth authors. The first and

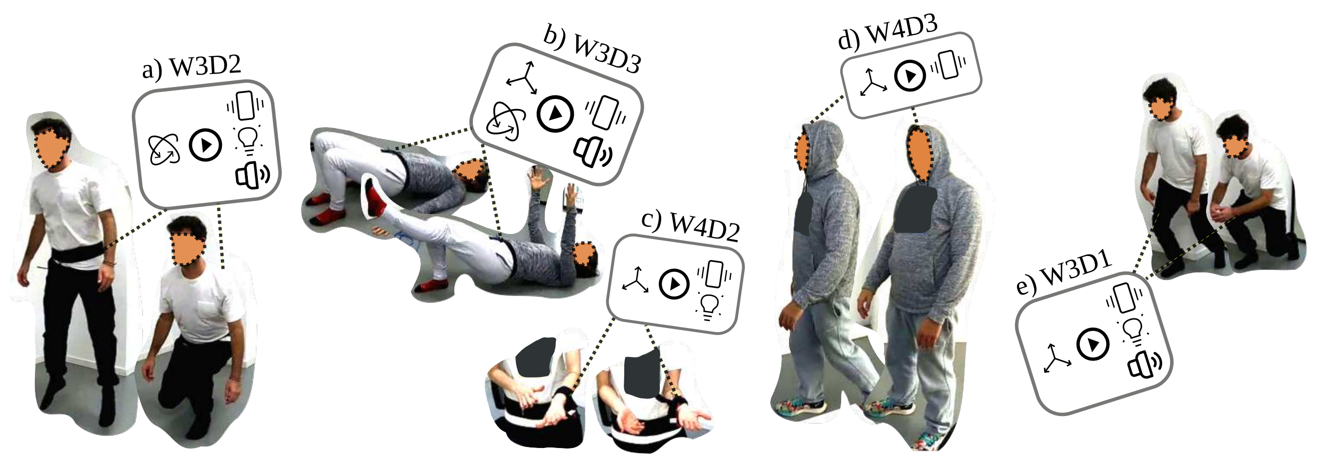

Figure 7: A selection of designs resulting from the evaluation workshops.

second authors discussed the resulting insights from this analysis and elucidated their relevance for the wider Interaction Design and Human-Computer Interaction community and provided clear directions for deepening the analysis. After iterating and refining the analysis, the first and fifth authors discussed the findings and framed the themes for dissemination in the paper.

6 EVALUATION RESULTS

6.1 Overview of Results

In the four workshops, participants generated a total of 15 different ideas for wearables supporting movement learning across different movement practices, showcasing the generative potential of the Movits. Table 2 summarises these design ideas and provides an ID for them, detailing their application domains, wearable placements, input/output modalities, and the Movits that participants used as probes and references to develop and present their ideas during the workshops. Overall, the participants explored movement disciplines familiar to them—swimming, volleyball, archery, weightlifting, yoga—, specific rehabilitation or alignment exercises—such as those for gait rehabilitation or the recovery of joint range—, or self-care or creativity experiences—massage and choreographic exploration.

In this section, we discuss our findings regarding the roles of generated ideas (Sec. 6.2), to what extent they extended the interactions provided by the Movits (Sec. 6.3), the Movits that were used the most and the least and their impact on idea generation (Sec. 6.4), and to what extent and why the Movits were helpful in the participants' design processes (Sec. 6.5). Because our analysis was based on the written reports for each of the designs—some of which were created collectively—and not on the conversations or individual comments by the participants, we report our findings by referring to the ID of the involved designs. Additionally, note that most of the time we report our findings without emphasising if they originated from professional physiotherapists or not. This speaks to our interest regarding the workshops as standalone and holistic experiences but might be a limitation of our results.

6.2 Roles of Generated Ideas

To evaluate the designs, we employed as a lens the classification of Turmo Vidal et al. [52] (Fig. 6.a) regarding the possible roles of the *outputs* of wearable technology for sports and fitness practices. The Movits provide immediate feedback to the wearers' actions, and therefore the most straightforward role for all of their outputs is to provide *information* in the form of *feedback* which consists of *knowledge of performance* [52]. Because of this, it was not surprising that most of the ideas presented applications where some kind of *knowledge of performance* was supplied, be it an indication of misalignment—such as in W1D1, W2D1, W2D3 or W4D3—or a reward for arriving to a desired position—such as in W1D2, W3D1, W3D2 or W4D2. We were interested in evaluating to what extent the generated ideas would extend this base role and explore others.

We found it illuminating that several designs selected and focused on another possible role, the *experiential qualities* that the Movits provided to the participants. For instance, W1D4, W2D2, W2D4 and W2D5 highlighted the experience of the vibrotactile haptic feedback on their bodies, and W1D4, W2D2, W3D3 and W4D1 focused on the sound of water emitted by the MotionPlaySample Movit. W2D5 and W3D3 were also interested in the *experiential qualities* of the possibilities of social connection while using their designs in a group. In the case of W1D4 and W2D2—the two designs focused on wearables for providing a holistic recovery massage—, the *experiential quality* was their only focus and they did not consider the role of *providing information.* The emphasis on the felt experience and experiential qualities of these designs reminded us of slow, introspective and reflexive Soma Design processes which inform our work—such as those described by Núñez-Pacheco and Loke [29, 30], Windlin et al. [56, 57], Søndergaard et al. [40, 41] or Alfaras et al. [2]—even if that was not the default mood of the workshops. We observed that the designs that considered the experiential qualities emerged in all four workshops and thus were not restricted to a specific population. From this, we gather that the Movits have the potential to be used effectively as probes in somaesthetic appreciation design [13] workshops.

ID	Application	Placement	In	Out	Movit(s) used as Probe(s)
W1D1	Arm alignment in archery	Forearm	O	L V	TiltPlayVibration
W1D2	Augmentation of weightlifting	Arms and Legs	O	L S V	TiltPlayNote
W1D3	Swimming pacing	Ears and Waist	O	L S V	TiltPlayVibration, TiltToVibration, TiltToMetronome
W1D4	Recovery massage	Hand	M	L S V	MotionPlaySample
W2D1	Swimming stroke technique	Forearm	O	S V	TiltToMetronome
W2D2	Recovery massage	Hand	O	L V	TiltPlayVibration
W2D3	Artistic swimming synchronization	Head, Elbows, Wrists, Knees, Ankles	O	V	TiltPlayVibration
W2D4	General alignment in yoga	Waist, Wrists, Knees	M O	L S	TiltToMetronome, MotionPlaySample
W2D5	Dance creativity stimulation	Top of Head, Wrists, Ankles	O	V	TiltToVibration
W3D1	Ankle mobility in volleyball	Thigh	O	L S V	TiltPlayVibration
W3D2	Jumping technique in volleyball	Waist (back)	M	L S V	MotionToPitch
W3D3	Lumbopelvic stability	Waist (front)	M O	S V	TiltPlayVibration, MotionPlaySample, MotionPlayVibration
W4D1	Scapular rehabilitation	Shoulder blades	M	S	MotionPlaySample
W4D2	General joint rehabilitation	Head, Waist, Forearm	O	L V	TiltPlayVibration
W4D3	Gait rehabilitation	Top of Head	O	V	TiltPlayVibration

Table 2: Overview of the resulting designs in our four evaluation workshops. Abbreviations: Inputs: O is Orientation, M is Motion; Outputs: L is Lights, S is Sound, V is Vibration.

Finally, some designs also considered the roles of providing *feedback* in the form of *knowledge of results* [52] and some others the role of supplying *feed-forward*. For instance, W3D1, W3D2, W3D3, W4D1 and W4D3 involved a reporting of the *results* of the activity. Those were all designed by physiotherapists, which might speak to their involvement in the evaluation and improvement of the conditions of their patients and the interest they might have in quantifying results. Regarding *feed-forward*, W2D1, W3D1 and W3D2 considered their design could provide instructions and objectives of the activity to perform, and W1D3 was inspired by the sound of TiltToMetronome to use it as a feed-forward mechanism to indicate the desired pace. It appears that the Movits helped to some extent to provide a framework for designing complete experiences with *feed-forward* of objectives and *feedback of results* even if by themselves they only supply *feedback of performance*.

6.3 Features of Designs

We also analysed the proposed features of the designs regarding their intended interactions. We were especially interested in the input and output modalities they chose, and to what extent they extended or subtracted from what their chosen Movits did.

First, we observed that most designs—11 out of 15—had *multimodal* outputs, and for those four that were *monomodal*, three chose vibration and one sound as outputs. No design chose lights as their only output, which might speak to the stronger stimuli that vibration and sound provided to participants. Additionally, six designs—W2D1, W2D3, W2D5, W3D3, W4D1 and W4D3—explicitly expressed that they would remove the lights as they were not helpful to their applications. This validates our decision to have chosen vibration and sound as the main outputs of the Movits.

Interestingly, of the 11 multimodal designs, 10 included vibration as one of their output modalities. In six of these cases, the vibration was part of the chosen Movit, and in the remaining four it was added by the participants as a complement to a sound-based interaction. It seems that, as all participants tried vibration-based Movits—at least during the introductory phase of the workshop—they kept a strong impression of the sensation and wanted to incorporate it in their designs. This might speak about a potential *intimate correspondence* [13] induced by the synchronisation of participants' movements with the haptic stimuli. The participants who added vibration to a Movit interaction that did not have it—W1D2, W1D4, W2D1, W3D2—mentioned that they included it because they found it more personal or direct to convey localised feedback. All of these findings echo prior work discussing the roles of vibrotactile haptics as a feedback mechanism for movement [42]. Regarding further findings regarding vibration, the three designs in Workshop 3 had vibration as an output. They noted this type of feedback would be appropriate for group work as long as it was accompanied by lights or some kind of visualisation so that the instructor of the activity would know what would be happening with each individual. This confirmed the principle of *shared frame of reference* of intercorporeal biofeedback [48] without us having to mention it. Other designs with vibration as an output—W1D3, W1D4, W2D1, W2D2, W2D5 and W4D3—observed that vibration would be beneficial for individual and introspective activities, and some of them even chose it as their only output.

Regarding sound as an output, all of the nine designs which employed it introduced it from their chosen Movits. That is, no design that was vibration-based decided to incorporate sound. In those designs with sound, the types of sounds provided by the Movits were considered appropriate. The role of the water sound in the MotionPlaySample Movit is discussed below in more detail (Sec.6.5.3). A couple of projects—W1D3 and W3D1—explicitly indicated that they would add alert sounds to indicate both that an objective had been achieved or that there was some deviation. In the case of W1D3, these alert sounds would contrast with the sound of the metronome they would be using. However, there was not a detailed discussion about what type of alert sounds. From this, we gather that in future workshops like these, it could be helpful to have more sound samples—either in the Movits or in another system—so that participants have clearer options to select from. This echoes prior findings and discussions regarding the availability and types of sounds, and the metaphorical associations to them that can help in performing physical activity [18, 35, 42, 50]. Discussing group work in general during Workshop 3, and also in the case of W1D3, the participants realised that the sound-based outputs of their designs could be routed individually to their users via headphones, or switched off altogether. Depending on the context of the designs we would like to help instigate, we note it would be helpful to at least have some pairs of headphones in the bodystorming basket [54] for these workshops. The presence of headphones could point towards the possibility of their designs using them, even if the Movits per se cannot be connected to them—at least in this iteration.

Finally, we observed seven instances of designs—W1D2, W1D3, W2D1, W2D3, W3D1, W3D2 and W4D3—that envisaged a mobile *app* to either configure or visualise the outputs of their designs. Regarding configuration, four designs—W1D2, W2D4, W3D1 and W4D2—proposed a procedure to calibrate the working zones of the devices with start and end zones, echoing the calibration processes of Singh et al. [35] or Ley-Flores et al. [18]. Three designs—W3D3, W4D1 and W4D3—considered the possibility of adjusting the sensitivity of their devices to adapt it to the type of movement and body of the person that would use them. It was out of the scope of the workshops to further define the user interfaces and wireless interactions that these ideas would require. However, we highlight that the Movits worked effectively as ideation probes that could provide the basis for comprehensive designs even in the relatively short time we had for each of the workshops.

6.4 Selected Movits

We observed the frequency of use of the Movits and analysed the type of applications that they supported as ideation probes. Here we discuss the three most used ones—TiltPlayVibration, MotionPlaySample and TiltToMetronome—and the ones that were not used at all—the Touch Movits (see Table 2).

TiltPlayVibration was the most used Movit, as it was the basis in eight out of 15 designs. In six of these—W1D1, W2D3, W3D1, W3D3, W4D2 and W4D3—it inspired applications related to alignment which would use it basically as is: when a threshold of tilting angle would be crossed, it would start vibrating to indicate that either some position was achieved or some misalignment happened. The other two designs—W1D3 and W2D2—would use this Movit as an inspirational seed to work with vibration in general. In any case, it seemed that the interaction provided by the TiltPlayVibration Movit was the most straightforward to understand and elicited feedback that was both interesting and familiar. We observed that participants were able to obtain the vibration output regardless of the speed of the movements they were trying or the axis of rotation they chose. Even if at first they did not identify the middle point where the Movit started to vibrate, they could notice and activate its two states. For us, the popularity of this Movit in these workshops is very interesting from the perspective of minimalism, because its interaction can be implemented without a microcontroller, by either using simple tilt switches as discussed by Hartman et al. [8] or handcrafting a soft tilt sensor following the kit-of-no-parts [32] approach. We contend that the generativity and applicability of this probe are very high compared to the low complexity of its interaction, and therefore could serve as a good pointer towards further explorations of minimal interactions.

MotionPlaySample and TiltToMetronome were used four—W1D4, W2D4, W3D3, W4D1—and three times—W1D3, W2D1, W2D4—respectively. With their sound-based behaviour, they seemed to illustrate appropriately the input modalities of motion and orientation. MotionPlaySample kept its main behaviour across the four designs that used it as an ideation probe: all of them reacted to movement and played a sound. All of them kept the water sound because they enjoyed it, although in W4D1, the physiotherapist also considered using the wind sound available in the Movit, or another one, to be chosen by the user. We would be interested in exploring to what extent the usage of the MotionPlaySample Movit changes depending on its default sound sample. In the case of the behaviour of TiltToMetronome, although we observed it helped to illustrate the continuous nature of the orientation input, the proposed interactions based on it were beyond this mapping. For instance, in W2D1 and W2D4, the envisioned behaviour involved a range of ideal positions where the design would not produce sound. Outside of this range, the device would emit the metronome sounds with an increasing frequency depending on how far it was. In W1D3, the third design that used TiltToMetronome, the sonic behaviour of the Movit was implemented but decoupled from its orientation sensing. From the usage of both of these Movits, MotionPlaySample and TiltToMetronome, we enrich our observation from above (Sec. 6.3) regarding the availability of different sound samples that can be generative by themselves, without the need for complex interactivity. We also validated our selection of sounds: these two Movits are the ones—so far—that produce real-world samples instead of pure tones, which might have helped in them being selected more times.

Lastly, we found it interesting to observe that even though the Touch Movits were explored and selected by a couple of participants during the Discover (Sec. 5.2.1) of Workshops 2 and 3—when they were available as probes—, none of them were used in the Deliver phases (Sec. 5.2.4) and therefore were not considered by the participants as part of their designs. From what we could gather, it appeared that the interactions provided by the Tilt or Motion Movits were seen as more rich and inviting, especially for wearable technologies. The participants who further explored the Touch Movits—and who ended up designing W2D1 and W3D3—had difficulties coming up with possible applications regarding the two separate parts needed to complete the interaction: the placement of the device and the significance of the touch that would trigger it. In contrast, the Tilt and Motion Movits seemed to provide many possibilities as the placement of the device and the movement that would trigger it tended to be tightly coupled. From this situation, we gather that the further minimalism manifested in the Touch Movits possibly prevents their usage when there are other richer and more stimulating Movits in the kit. It seems that, depending on the intended application domain of the embodied sketching [28] activities planned for the Movits, and in case the Touch Movits are anticipated to be relevant, it would be pertinent to consider an alternative way of engaging with them.

6.5 Effectiveness of the Movits

As part of the documentation sheet and the final discussion, we asked the participants to reflect on to what extent the Movits had helped or not with their creative processes, and why. We also asked them about possible modifications they would want to apply to the Movits to be more effective.

6.5.1 Physical Features. Some of the participants focused on the *physical* characteristics of the Movits. For instance, participants found them to be helpful because of their small size, low weight and compact shape—W1D2—, their lack of cables—W2D3—, the way they can be attached to straps or clothes and be worn—W2D3—, and their physical robustness—W1D2. With this feedback, we validated our choices of using Adafruit boards, covering them with fabric and trying to keep external components as minimal as possible to allow participants to feel empowered to explore. Nevertheless, some participants—W1D1, W2D3, W2D4—would have preferred the Movits to be even smaller as they found them relatively obtrusive, especially for placing them on the head and wrists. Also, even though some groups—W1D3, W2D4, W3D3—presented their design by physically putting together two or three Movits, speaking well to their modularity, a smaller size could have benefitted them as well. Regarding another physical aspect, the groups of W1D2 and W2D4 expressed they would have preferred the Movits to have adjustable straps already fixed on them, instead of having velcro to attach them freely to straps or clothes.We take all this feedback for future work, as we would like to keep the physical modularity and flexibility of the Movits while also providing an invitation to explore their wearability in different body parts.

6.5.2 Feedback Features. Other participants commented on the effectiveness of the Movits because of features of the *feedback* they provide. They appreciated that it was immediate and precise and that therefore they could intuitively figure out how to use it and find possibilities for it—W1D2, W1D3, W2D4, W3D1, W4D3. They also commended that it was open-ended and therefore they could assign different meanings for it. For instance, in Workshops 3 and 4 the physiotherapists observed and discussed how the vibration of the TiltPlayVibration Movit was used as an indication of misalignment by some—W3D3 and W4D3—or of the achievement of an objective by some others—W3D1 and W4D2. In the case of W4D1, the design described that its sounds could be used to indicate something to achieve or something to avoid depending on the exercise. This all speaks strongly to the characteristics of *shared frame of reference* and *fluid meaning allocation* put forward by the strong concept of intercorporeal biofeedback [48], which grounds our work.

6.5.3 Usage Experience. We also received feedback praising the *experience* of using and exploring the Movits. In the four workshops, participants commented that they found the Movits intriguing and inducing curiosity, which made them engage with the activity. A student in W1D1 observed that at the beginning they were not motivated and did not want to participate, but once they started exploring the Movits, they enjoyed the process and were surprised by the amount of ideas they were coming up with. We find that this is in line with the mood that embodied sketching [28] aims to facilitate, and we were glad to observe that the Movits could support it. Some other participants took a more somaesthetic [13] perspective and commended the sensations induced by the Movits, either by their vibrotactile or sonic feedback. As we discussed above (Sec. 6.3), 12 designs included vibration as one of their outputs, in part because they considered that it provided them agreeable sensations. Interestingly, all the participants who chose to work with the MotionPlaySample Movit—W1D4, W2D4, W3D3, W4D1—expressed their fondness for the water sound it produced and the relaxation it induced. Some of them—W3D3, W4D1—connected it to the behaviour of a rainstick, which made them enjoy it more. This perception of relaxation and pleasure while listening to the water sound echoes the previous findings of Ley-Flores et al. [17, 18]—which inspired us to use those samples—and validates its inclusion in our toolkit. Additionally, we consider that this varied appraisal of the experience of using and exploring the Movits speaks to their potential of being employed beyond movement learning contexts.

All of the participants, except for two, voiced that they enjoyed the general experience of exploring and creating with the Movits. The two people who did not enjoy the experience as much mentioned that they felt overwhelmed by the whole activity and did not feel confident enough to choose and develop a specific application. The designs that emerged from them were W2D4 and W4D2, which perhaps not coincidentally were the ones who established a very broad context for their application. However, even in those cases, we observed those participants realised the Movits they selected were flexible enough to be used in a variety of ways. One of them—W2D4—articulated why the Movits were useful to them as design probes, even if they were not satisfied with their resulting design. We conjecture that for these two participants, it could have been more beneficial to constrain their exploration regarding the design scenario or the amount of available Movits. Additionally, they might have benefited from having more allotted time.

6.5.4 Further Reasons. The physiotherapists in Workshops 3 and 4 also articulated a more analytical rationale of why the Movits worked in their processes and could work for other stakeholders in co-design workshops. They—W3D1, W3D2 and W4D3—observed that the Movits provided an *external focus of attention* [20, 60] that can be effective and malleable for different circumstances. They recognised that as such, it could provide more autonomy to their patients. Also, some of them asserted—W3D1, W3D2 and W3D3—that the Movits could measure and externalise useful information that is otherwise hidden from an observer—i.e., from them as physiotherapists interested in the movement features of their patients. We contend that these observations are aligned with the theoretical work behind the TTPs [25, 26, 45–47, 51] and the strong concept of intercorporeal biofeedback [48], which inform our work and validate its potential for movement learning applications.

7 FINAL REMARKS

We designed and evaluated the Movits, a minimalist toolkit for embodied sketching [28] composed of nine units that exhibit single interactions of multisensory feedback for movement-based inputs (Fig. 4 and Table 1). The input and output modalities and the mapping between them that we implemented (Sec. 3.4) are based on an analysis (Sec. 3.1) of toolkits for embodied design (Sec. 2.1) and projects of wearable technologies for sports and fitness practices (Sec. 2.2.3). The Movits were designed to mediate and support the social dimension of movement learning, and for this, they were grounded in the strong concept [14] of intercorporeal biofeedback [48] and its four interactive qualities.

We ran four embodied sketching workshops with different populations to validate the potential of the Movits as ideation probes for movement-based design explorations. From a qualitative analysis of the resulting designs, we gathered several insights. We validated their potential as generative probes: they allowed participants to come up with comprehensive ideas for multiple movement-based application domains. These ideas extended the interactions provided by the Movits, either by considering other types of inputs and outputs or other possible roles [52] of their technologies beyond feedback providing knowledge of performance—such as knowledge of results, feed-forward of instructions, and even a focus on experiential qualities. In this way, we contend that the minimalist setup of the Movits, along with the chosen modalities of inputs and outputs, proved to be *necessary and sufficient* [33] enough to support and reflect more rounded and polished movement-based designs, such as those in the multiple projects reviewed.

Speaking to the adaptability of the Movits, we found in them a potential to aid in somaesthetic appreciation [13]. We observed that the Movits were effective as probes to explore experiential qualities of multisensory feedback in a way that echoed slow, introspective and reflexive Soma Design processes which inform our work [2, 29, 30, 40, 41, 56, 57]. Based on these results, we contend that, by providing the possibility of exploring movement-based interactions with multisensory feedback, the Movits have the potential to be used effectively as probes in soma design [12, 13] workshops.

In general, we observed that the minimalism we embedded in the Movits was helpful and empowering for the participants of our workshops. Their small size and modularity enabled them to explore multiple placements in their bodies, to wear them comfortably, and to join two or three together to explore more complex interactions. The participants were able to quickly make sense of the feedback that the Movits provided and explore creative applications in movement-based interactions. This echoes prior work in embodied ideation toolkits (Sec. 2.1) and extends those findings to the application domain of movement learning.

We also confirmed the grounding of the Movits in the strong concept [14] of intercorporeal biofeedback [48] and its four interactive qualities. During the evaluation workshops, their open-ended audiovisual or visuotactile feedback helped to provide *shared frame of reference* for the conduction of a movement, allowing for a *fluid meaning allocation* of its behaviour. By being minimalist, we observed that they were likely to favour *guiding attention and action* toward and away from them and admit being used along other objects and activities, as an *interwoven interactional resource*.

With this work, we contributed an account of the design process of the Movits as a model of simplification and generalisation of proven interactions in wearables for movement practices and embodied design toolkits. We found that the analysis of inputs and outputs, and its subsequent application to a specific domain, generated modules that were themselves generative and adaptable. We designed the Movits so that they can be replicated and used by other designers and researchers working with embodied sketching and soma design. Additionally, we contend that the findings of our evaluation workshops extend prior knowledge and can be applicable for the further design and research of toolkits and probes, as well as to the design of technologies which consider a holistic approach [12, 28] in their interactions.

Future work includes at least two possible directions. On one hand, we foresee further research regarding the design of the Movits. We still have to evaluate the degree of configuration embedded in each Movit, navigating the tension between making it more specific for an application while allowing a straightforward understanding of their behaviours. For example, we imagine that it could happen that instead of having one Movit—and therefore, one board and microcontroller—per interaction, it would work to have a single Movit with switches to toggle the types of inputs, outputs or mappings they exhibit. This tension is amplified by current discussions [9] regarding the economic and environmental costs of physical interfaces. On the other hand, we aim to use the Movits in further co-design workshops targeting wearable technologies for movement learning within a more specific domain, involving the participation of movement and health professionals, patients, and interaction designers. For these, we intend to use not only the Movits but a bodystorming basket [54] with relevant probes and materials which have been proven effective for embodied design. We regard that by involving embodied sketching [28], soma design [12, 13] and intercorporeal biofeedback [48] as the theoretical background for these participatory design explorations, we will hold space for meaningful explorations of movement-based design and technology by the people that would interact with it.

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