Towards a Minimalist Embodied Sketching Toolkit for Wearable Design for Motor Learning

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Figure 1: A selection of probes in our toolkit shown in use along the graphical representations of their behaviour.

ABSTRACT

Inspired by the strong concept of Intercorporeal Biofeedback, here we present the design and development of a minimalist embodied sketching toolkit for designing wearables for motor learning. The toolkit includes technology probes featuring minimalist wearable digital units that support hands-on explorations and the design of potential future interactions driven by movement with multisensory feedback. These units are self-contained and generate audiovisual or vibrotactile patterns in response to body inputs such as movement, spatial orientation, and touch. Here, we present and characterise the toolkit, together with its theoretical and empirical grounding and the design values driving the design process. The toolkit can be useful for those interested in an embodied design approach to designing wearables in general, and specifically for those targeting movement, such as in motor learning application domains. It can complement and be used with other assorted non-digital objects during Embodied Sketching sessions, like bodystorming.

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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

A *bodystorming basket* [32] is a tool prominent in embodied design ideation methods, such as Bodystorming for movement-based interaction design [15] or Sensory Bodystorming [31]. It consists of a collection of simple and diverse props for ideation, often featuring particular relevant properties to the target application domain [32]. A bodystorming basket might contain objects such as common crafting materials and everyday objects like cardboard boxes, tape, sticks, balls, toys, lights, children's musical instruments, dolls and hand puppets [32]. Even though the use of *bodystorming baskets* [32] with assorted, non-digital objects, is common, there have been instances of a need for particular affordances and interactive capabilities that these objects could not provide. To address this need, designers often resort to available cheap and simple off-the-shelf technology, e.g. interactive toys for pets and children and tools for relaxation and massage [3, 32]. While these simple gadgets might trigger interesting explorations of multisensory aspects, some design activities might require exploring more nuanced or concrete multisensory signals and feedback. Hence, ad hoc technology probes are needed.

We designed and developed a toolkit of minimalist technology probes—simple, flexible and adaptable technologies for inspiring users and researchers to ideate new technologies [7]—in the form of relatively small and simple wearable digital units that support hands-on explorations and the design of future interactions driven by movement and using multisensory feedback. Our toolkit uses hardware such as multicolour lights, buzzers or vibrating motor discs to generate audiovisual or visuotactile patterns in response to body inputs such as movement, spatial orientation, or touch. For the sake of simplicity and to aid in the facilitation of embodied design workshops, the units are self-contained: each one runs a single, straightforward interaction and they do not communicate with each other.

The units originally emerged in the context of a research project to co-design wearables for motor learning applications based on multisensory feedback as tools to support participatory and embodied design workshops involving interaction designers, engineers, movement and health professionals in the areas of rehabilitation, physical therapy and occupational therapy, along with their patients. The project draws from new rehabilitation techniques tackling sensorimotor learning [6, 21], in turn grounded in a growing body of evidence supporting the notion that body perceptions are not fixed but continuously updated by body-related multisensory feedback [2]; and from computational theories for motor control, from where it derives that planning and execution of motor actions can be partially altered by augmented or distorted external multisensory feedback [36]. Furthermore, our work is inspired and informed by the practice of Embodied sketching [16] and the strong concept of Intercorporeal Biofeedback [30] for movement learning, described below. Because of its grounding, even though the toolkit has emerged for a specific application domain, we envision it has the potential to be used in a broader context.

2 BACKGROUND

2.1 Inspirational Seeds

Here, we present approaches, concepts, and general knowledge areas that inspire and ground the creation of the toolkit.

2.1.1 Embodied Sketching. Embodied sketching is an Interaction Design (IxD) practice that involves physically and playfully exploring, understanding, and designing embodied experiences early in the design process [16]. Embodied Sketching encompasses design methods grounded in the lived bodily experience of stakeholders—for instance, *sensitising* of designers, which implies engaging with key actions and experiences relevant to the target domain/design; *bodystorming*, through playfully and physically engaging in ideation activities; and *co-creation* and iteration of design prototypes with designers and participants or users. It takes an embodied approach to ideation that is activity-centric [33], physical, hands-on, playful and movement-based. [16]. It bears a holistic understanding of design, considering diverse design resources, including spatial and social settings, movement and objects, along with digital technologies.

2.1.2 Intercorporeal Biofeedback. Intercorporeal biofeedback [30] is a strong concept [8] that proposes the role of interactive technology as "a mediator supporting the social dimension of movement teaching and learning" [30]. It presents a way to design open-ended biofeedback technology to achieve this role. The concept was developed based on movement practices such as circus and strength training, involving practitioners taking either the role of teachers or students [30]. This social component aligns well with our project, involving physiotherapists, rehabilitator physicians, and surgeons teaching concrete rehabilitation exercises, but also learning about movement capabilities, and difficulties the patients experience. Furthermore, the social component of intercorporeal biofeedback is highly relevant to facilitate joint meaning-making and co-creation in the context of participatory embodied design activities.

Intercorporeal biofeedback is characterised by four interactive qualities: (1) shared frame of reference; (2) fluid meaning allocation; (3) guided attention and action; and (4) interwoven interactional resource [30]. The first characteristic refers to the capacity of biofeedback to be perceptually accessible (through using e.g. audiovisual or visuotactile and not only vibrotactile feedback) to teachers and students at the same time, which helps create a frame that both parties can refer to and draw from [30]. *Fluid meaning allocation* refers to designing technology to support in-the-moment constructive meaning-making by teachers and students. This is done through designing open-ended technology feedback that is made meaningful *in context* by them [30]. Open-endedness is key for this purpose, contrasting to other approaches that measure and present movement data in a normative way, e.g. by limiting feedback to a specific and constrained type of motion or providing measures of "correctness" in execution. *Guided attention and action* concerns how these technologies can enable a focus of attention fluctuation from the body to the biofeedback, their relationship, or the instructions provided by observing peers [30]. Finally, *interwoven interactional resource* reflects a holistic perspective of movement learning, in which the technology takes a complementary role in interaction with other resources and strategies used as part of movement learning practices. Hence, technology based on intercorporeal biofeedback should not be the sole focus of a lesson, but another resource that can be used with, e.g. verbal instructions, demonstrations, and material equipment [30].

2.2 Related Toolkits and Probes

The following is an overview of related toolkits and probes that have been developed to address a similar gap in their *bodystorming baskets* [32]: the need for ad-hoc technology probes to explore more nuanced or concrete multisensory signals and feedback, a more fine-tuned control of actuators, or additional affordances than those provided by simple gadgets. For instance, the Inspirational bits [25] were developed as a way to expose the workings of common technologies for Human-Computer Interaction (HCI), such as Bluetooth, RFID, accelerometers and Wireless Sensor Networks. The research team designed a few probes to illustrate the different properties of a single technology. This resonates with our approach to developing multiple units to allow the exploration of a given input modality. We differ in that the context for our toolkit is embodied sketching for movement-based technologies.

More recently, the Soma Bits [34, 35] 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. 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. These objects have been used to support soma design processes. Our work is similar to the Soma Bits regarding the values of minimalism and the holistic understanding of embodied experiences, where technology is not the sole focus. However, our work differs in the output modalities we use—our only overlap is vibration—and in the way we trigger and modulate them: the Soma Bits use a controller-based approach using switches and knobs whereas we use movement-related inputs. Related to the Soma Bits, the Felt Sense Glove [17, 18] and Sense Pouch [18] supported an exploration of the effects of heat and vibration in people's somatic experiences. These probes were used along the Focusing somatic technique. The Felt Sense Glove was an interactive glove providing vibration when touched, and the Sense Pouch was a small cushioned bag that would either house a vibrating device or a small hot water bag [17, 18]. From these probes, we informed our decision to use soft materials for the enclosures of our units.

More directly related to our project—although not described as a toolkit by the authors—, there are the Training Technology Probes (TTPs) [13, 14, 29]. These are a collection of wearable devices that augmented and exteriorized the *movement senses*—proprioceptive and vestibular senses. They provided multisensory feedback with lights, sound and vibration mapped to orientation or motion. The TTPs were used and reappropriated in teaching and learning sessions of movement disciplines such as yoga, circus training and weight lifting [13, 14, 29]. They were easily adaptable, flexible and versatile, and they comprised the empirical grounding of the Intercorporeal Biofeedback strong concept [30]. We build our toolkit upon them, because we share with them the foundations of this strong concept, along with design guidelines such as minimalism and self-containedness. However, our work differs in the analytical way it separates output modalities of sound and haptics and in the way it extends the inputs to include touch and pressure.

Finally, there is a line of research concerned with designing modules that can be interconnected and used to explore and prototype wearables and e-textiles. The Wearable Bits [9] are a modular set of patches of different levels of fidelity with common electronic components—sensors and actuators—that can be arranged according to one's design and prototype. The Kit-of-No-Parts approach by Perner-Wilson et al. [20] consists of handcrafting textile interfaces—such as tilt, pressure or stroke sensors—from scratch so that one can personalize, understand and share them. Both the Wearable Bits and the Kit-of-No-Parts approach inspired the minimalism and (relative) low complexity in our toolkit and have pushed us away from a tendency of technocentrism.

3 DESIGN GOALS

Our toolkit draws on the intercorporeal biofeedback [30] strong concept using the four above-described characteristics (2.1.2) to shape our design goals and envisioned *preferred state* [37]: 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 and 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 [16]: sensitizing, ideating and prototyping, in particular in the context of movement learning experiences.

To design our toolkit, our objective was to design minimal units reflecting pre-existing proven interactions in open-ended wearable projects for movement-augmented feedback. *Minimal* here refers to simplicity, i.e. *low complexity*. Towards the design of a first set of these units, this would mean that the devices 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 devices should work *offline*, i.e. without Wi-Fi or other wireless communications. This would support in-the-wild embodied sketching (e.g. outdoors), and keep the focus on embodied action rather than on troubleshooting potential problems and reducing technical complexity during embodied design workshops. We left for future work relatively more complex design units implementing, e.g. communication. For now, and for the early design stages that this toolkit targets, we are contented with such interaction between devices being able to be simulated or puppeteered in a Wizard of Oz manner [4].

We envision that this toolkit should be reproducible in a variety of research contexts involving movement-based design. To help in that regard, we were interested in developing it so that it was not tied to a specific platform. For this, we started selecting a preliminary set of main inputs of our devices: *orientation*, *motion* and *pressure* or *touch*, and their possible outputs to *sound*, *lights* and *vibrotactile haptics*. These result from the analysis of relevant projects that we describe in the section below.

4 ANALYSIS OF RELEVANT PROJECTS

We analyzed several projects of wearable and open-ended technologies for movement learning and augmented feedback taken from the work of Turmo Vidal et al. [30] on Intercorporeal Biofeedback and further related work. We reviewed the resulting designs in these projects through the lenses of our design goals.

The reviewed projects included technologies for augmented and multisensory feedback in circus (*LISTO* and *TRAP* [22], *SonicHoop* [12], and *TTPs* [13, 14, 29]), weightlifting (*GymSoles* [5]), winter sports (*Augmented Speed-skate Experience* [24] and *Motion Echo Snowboard* [19]), yoga (*TTPs* [13, 28, 29]), or physiotherapy for chronic pain (*Go-with-the-Flow* [23]), technologies for transformation of body perceptions to support physical activity (*Soniband* [10, 11, 26], *Sonishoes* [26, 27] and *Vibratory patterns* [26]), and technologies for, or resulting from, soma design explorations (*Sounds of Synchronous Movements* [1], *Felt Sense Glove* [17, 18] and *Sense Pouch* [18]).

From these projects, we gathered the kinds of inputs—*orientation*, *motion* and *pressure* or *touch*—, outputs—*sound*, *lights* and *vibrotactile haptics* and the input-output relationships which were in use (see Table 1), and took them as the basis for our design. Our analysis yielded other interesting input or output modalities, such as biosignals [1] or knobs [34, 35] as inputs, or heat [18, 34, 35] and shape-changes (inflation) [34, 35] as outputs. Yet, we chose to craft a first iteration of the toolkit implementing more simple modalities in terms of setup, implementation, and use, which could still support and reflect more rounded and polished designs, such as those in the multiple projects reviewed.

The resulting input-output relationships could be roughly 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. For example, the brightness and hue of light colour were proportional to the pressure measured in *Motion Echo Snowboard* [19]. 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. For example, when a threshold of measured pressure was crossed in TRAP (Trigger Responsive to Applied Pressure) [22], a set of lights was turned on. We created a graphical language to illustrate the inputs, mappings and outputs resulting from our analysis and then implemented them in our design (See Figure 2). These illustrations would help us design and represent the different building blocks of our toolkit.

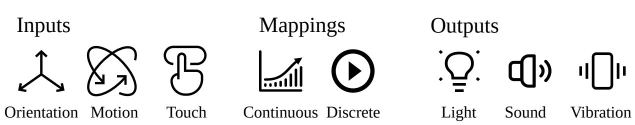


Figure 2: Graphical representation of our building blocks for inputs, mappings and outputs. Icons provided by Miro.

We gathered that certain input-output combinations were more represented along the set of projects we analyzed. For instance, several of them provided auditory feedback to orientation inputs whereas only one—*Vibratory patterns* [26]—could provide haptic feedback mapped to the amount of motion. For our design, we decided to convey all the possible mappings shown in Table 1. The more represented ones have been validated already and we could take inspiration from them, either simplifying them in terms of behaviour, hardware and software or providing variations e.g. in terms of sound quality or configuration of axis of rotation. For the less represented mappings, we reasoned we could develop them and then explore if their lack of representation was due to them not being effective or because of an absence of a way to test them.

5 A PRELIMINARY TOOLKIT

The design of our preliminary toolkit consisted of developing one or two units per combination of input modality—*orientation*, *motion*, and *touch* or *pressure*—with output modality—*sound* or *haptics*. We decided to provide *all* units with coloured light coupled to the sound or haptic output they provide, therefore making them provide either *audiovisual* or *visuotactile* feedback. In this way, their bi-modal output is intended to assist the *shared frame of reference* between wearers and audience as postulated by intercorporeal biofeedback [30]. The output of each of the units was designed to be open-ended—thus likely allowing for a *fluid meaning allocation* [30] between their users—, and unobtrusive—so that it would be feasible to *guide attention and action* [30] toward and away from it, and it could potentially blend well as an *interwoven interactional resource* [30].

We designed four units based on Orientation, three units based on Motion, and two units based on Touch. Developing one or two units per input-output combination was contingent on the possibility of implementing the two types of mappings from our building blocks (Fig. 2), continuous and discrete. Figure 3 presents an overview of these units in the form of a photo accompanied by a graphical representation of the behaviour of each one. This section presents a more detailed description of each one.

5.1 General Characteristics

We developed our toolkit using Adafruit Circuit Playground Express and Gemma M0 boards, along with LilyPad components—vibration motors, buzzers, switches, and buttons. We decided to use these boards because of their assortment of built-in components and capabilities—such as accelerometers, speakers, lights, buttons, and capacitive touch input—and their computational specifications which allow for simple sound processing and playback of short sound samples. Additionally, they reside at a middle ground regarding complexity in hardware and software, ideal for our design goals. For programming the units we used CircuitPython to leverage its support for beginners and allow for a simple re-configuration of its parameters should a more advanced session require it. For the physical construction of the units, besides the boards, we used e-textile materials such as conductive thread and fabric, soft enclosures and straps. The units 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.

5.2 Orientation Units

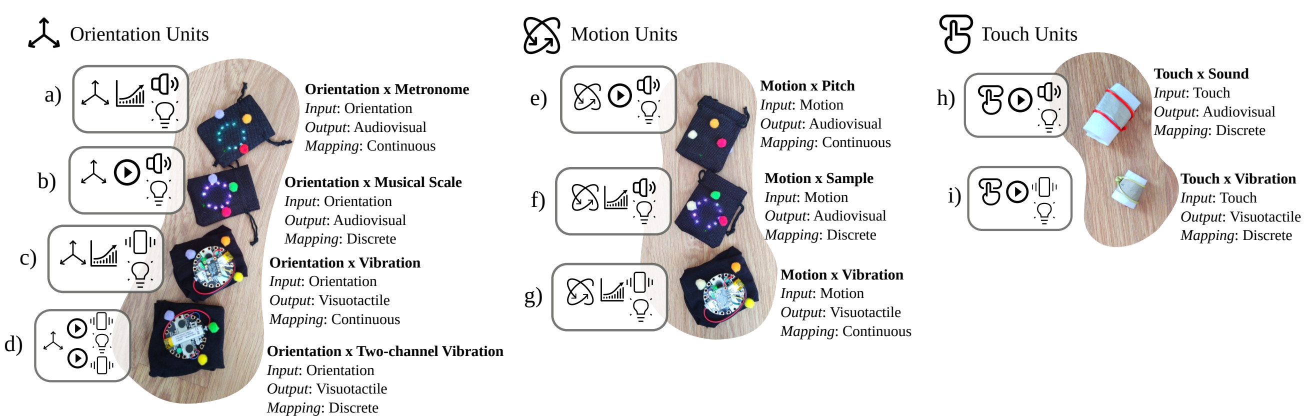
The units based on orientation calculate it from the gravity pull measured from the three axes in the accelerometer, assuming a relatively static position. As an input, they use the angle of rotation of the plane of the device around a single axis. The axis of rotation can be selected by pressing a button on the board. All of these units have a similar behaviour regarding visual feedback: they use a rainbow-like palette that is mapped to the full rotation of the units.

5.2.1 Orientation x Metronome. This unit provides a metronome that changes its frequency according to the angle of rotation. By pressing a button, one can select if the change in frequency is

Table 1: Overview of combinations of Inputs (left) and Outputs (top) in open-ended wearable projects for movement-augmented feedback.

	Sound	Light	Haptics
Spatial orientation	Go-with-the-Flow [23], Soniband [10, 11, 26], Sonishoes [26, 27], Sounds of Synchronous Movements [1], TTPs: FrontBalance, Tiltband, TopBalance [13, 14, 29]	FrontBalance, Laser, Tiltband and TopBalance TTPs [13, 14, 28, 29]	FrontBalance and Tiltband TTPs [13, 14, 29], Vibratory patterns [26]
Motion	Augmented Speed-skate Experience [24], Movement TTP [13, 14, 29], Soniband [10, 11, 26], Sonishoes [26, 27]	LISTO [22], Movement TTP [13, 14, 29]	Vibratory patterns [26]
Touch or Pressure	Augmented Speed-skate Experience [24], SonicHoop [12], SoniShoes [26, 27], BalBoa [14]	Motion Echo Snowboard [19], TRAP [22]	Felt Sense Glove [17, 18], GymSoles [5], Sense Pouch [18]

Figure 3: Overview of our toolkit



directly or inversely proportional to the measured angle. Its sound behaviour is inspired by the Movement and Tiltband TTPs [13, 14, 29], but instead of a pure tone for the sound, it uses a sound sample of a real metronome and provides the option to choose the axis of rotation. The coloured lights in this unit pulsate at the same frequency as the metronome. (Fig. 3.a)

5.2.2 Orientation x Musical Scale. In this unit, the full rotation of the unit is divided into eight angular sections of the same size. A note of the C major scale—in the form of sound samples from a piano—is assigned to each one of them. When the unit enters a given angular section, the corresponding note is played once. This behaviour is based on the *sonic phrase paradigm* of Go-with-the-flow [23], where a single scale is correlated to changes in orientation. In this unit, we assigned one colour of the rainbow-like palette per note. The coloured light stays on during each angular section. (Fig. 3.b)

5.2.3 Orientation x Two-channel Vibration. This unit contains two vibrotactile actuators—one at each side—and divides the full rotation into three sections: neutral, left and right. When the device is tilted and its orientation reaches the left or right section, it activates the actuator of that side. One can invert this behaviour by pressing a button on the board so that the opposite actuator gets activated. The lights on the same side of the activated actuator are lit and they change colour depending on the amount of tilt. This unit is based on the Tiltband and FrontBalance TTPs [13, 14, 29] but provides a simplified version in terms of form factor along with more customization in its behaviour. (Fig. 3.d)

5.2.4 *Orientation x Vibration.*

This unit uses a single vibrotactile actuator connected to a controller that allows modulating the intensity of vibration based on the angle of rotation. Similar to the Metronome unit, one can select with the press of a button if the change in intensity is directly or inversely proportional. (Fig. 3.c)

5.3 Motion Units

The units based on motion calculate and use the total absolute difference in the acceleration measured in the three axes between two points in time. In this way, movements that involve sudden changes in motion trajectory generate a greater value of motion than those that are slow or with a constant direction.

5.3.1 *Motion x Pitch.*

This unit emits notes of increasing pitch proportional to the amount of measured motion. This behaviour is mostly inspired by the Movement TTP [13, 14, 29]. The rainbow-like colour palette is mapped to the notes that are played. (Fig. 3.e)

5.3.2 *Motion x Sample.*

In this unit, when a threshold of motion is crossed, one sample of sound from a given collection is randomly selected and played. For instance, when one moves, one can hear sounds of splashing water, blowing wind, or rusty gears as if those sounds were generated by own's motion. The collection of samples can be selected by pressing a button on the board. This unit is inspired by Soniband [11] in both its behaviour and the types of sounds that are used, but it presents a simplified version of the system regarding requirements of hardware and calibration capabilities. In this unit, the lights are turned on when a sample is played and their colour is fixed and based on the chosen selection. (Fig. 3.f)

5.3.3 *Motion x Vibration.*

Similar to the Movement x Vibration unit, this unit uses a single vibrotactile actuator with controllable intensity. In this case, the intensity of vibration is proportional to the amount of motion. One can select with a button if the relationship is direct or inverse. In our analysis, we did not find an example of this behaviour but we decided to implement it to allow for its exploration. (Fig. 3.g)

5.4 Touch Units

Our Touch Units are devices partially covered by a conductive fabric. Touching the fabric activates an output—vibration or sound—that stays on until the touch is released. The output of these units is accompanied by a light turned on simultaneously. These units are based on the capacitive touch capabilities of our prototyping boards.

5.4.1 *Touch x Sound.*

This unit plays sound samples and turns a light on when touched. The samples are the same as our *Motion x Sample* unit, based on the work of Ley-Flores et al. [11]: they consist of water, wind, and rusty gear sounds. (Fig. 3.h)

5.4.2 *Touch x Vibration.*

This unit activates a vibration motor disc as long as it is touched. It is based on the Sense Pouch [18] and Felt Sense Glove [17, 18], but replaces their soft button with the touch of the fabric. (Fig. 3.i)

6 FINAL REMARKS

The toolkit presented here was initially designed to be used to support ideation in upcoming embodied sketching [16] workshops targeting wearable technologies for movement learning, with the participation of movement and health professionals, patients, and interaction designers. The units in the toolkit were designed to mediate and support the social dimension of movement learning, and for this, they were grounded in the strong concept [8] of intercorporeal biofeedback [30] and its four interactive qualities. Their open-ended audiovisual or visuotactile feedback is likely to provide a *shared frame of reference* for the conduction of a movement, potentially allowing for a *fluid meaning allocation* of its behaviour. By being minimalist, they are likely to favour to *guide attention and action* toward and away from them and admit being used along other objects and activities, as an *interwoven interactional resource*. In our upcoming workshops, we intend to evaluate to what extent the toolkit provides meaningful support to an otherwise conventional collection of physical probes in a bodystorming basket [32].

The input and output modalities and the mappings we implemented in our toolkit emerged from the analysis of existing projects that we used to frame our design. So far, we bounded our toolkit in this way because these modalities were representative enough of multiple projects of multisensory feedback for movement learning, and because they offered a relative simplicity in implementation and use. Future work would involve exploring further inputs, such as pressure, stretching, sound, temperature, electrodermal activity or electromyography, and outputs such as heat or inflatables. Additionally, we intend to evaluate and then expand, reduce or keep the degree of configuration or variation that each unit provides. We are interested in examining to what extent more controls for customization in a given unit provide added value in creative possibilities when taking into account the increased complexity in the learning curve for using it.

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