Flow: Towards Communicating Directional Cues through Inflatables

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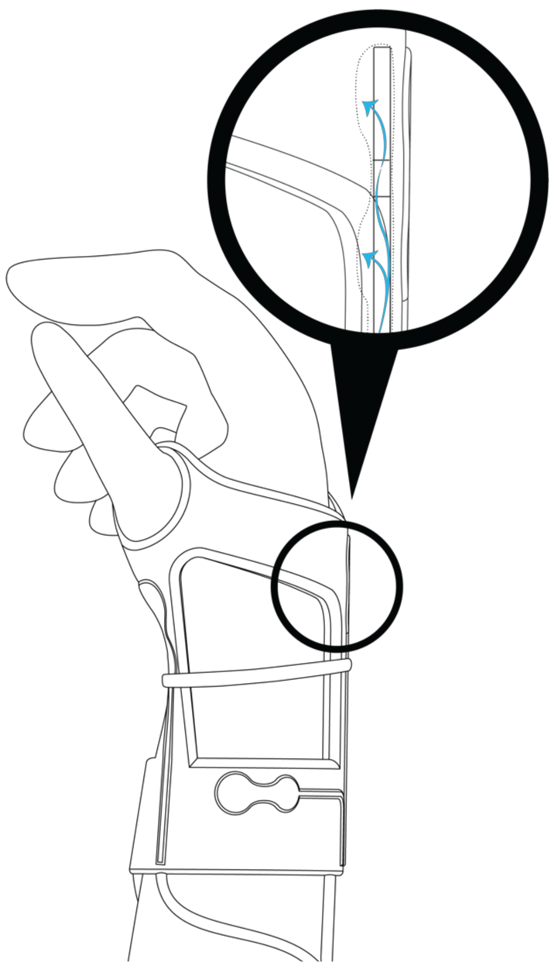

Figure 1: Middle cue point of Flow being actuated to prompt flexion of the wrist

ABSTRACT

Current research in wearable technologies have shown that we can use real-time tactile instructions to support the learning of physical activities through vibrotactile stimulation. While tactile cues based on vibration may indicate direction, they do not convey the direction of movement. We would like to propose the use of inflatables as an alternative form of actuation to express such information through pressure. Inspired by notions from embodied interaction and somaesthetic design, we present in this paper a research through design (RtD) project that substitutes directional metaphors with push against the body. The result, Flow, is a wearable designed to cue six movements of the wrist/forearm to support the training of elementary sensory-motor skills of physical activities, such as foil fencing. We contribute with the description of the design process and reflections on how to design for tactile motion instructions through inflatables.

KEYWORDS

Research through design; Embodied interaction; Soft actuation; Tactile motion instructions

1 RESEARCH CONTEXT

The ideas presented in this paper resulted from a research through design (RtD) project that aimed to explore how to support the learning experience of physical activities, such as foil fencing,

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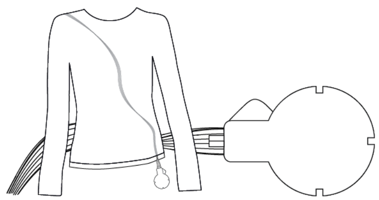
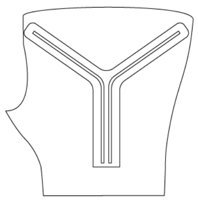
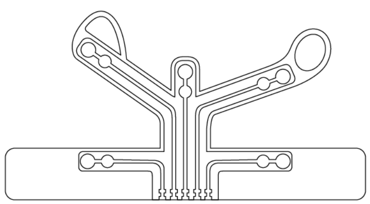


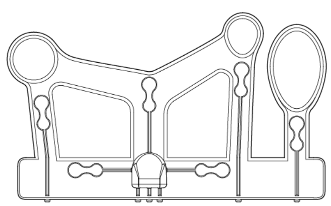
ITERATION 1 Vibration module attached to boning strip used as insert in a double layer shirt



ITERATION 2 Silicone 'y' shape with tunnels for metal wire inserts, embedded into a fingerless glove



ITERATION 3 Silicone artifact with five inflatable cues embedded into a rubber bracelet (open)



ITERATION 4 Final silicone artifact, with six integrated inflatable cues (open)

Figure 2: Project overview of the four main iterations of Flow

in an unmediated way. As vehicles for inquiry [13], our prototypes aimed to substitute directional metaphors with actual directional guidance through push against the body (Figure 1). Notions from embodied interaction [4] and a somaesthetic design [6] supported this transition. They elicited the use of the bodies of the designers as tools during the design process. Physically engaging with the materials during prototyping and first-person perspective explorations [12] enabled us to move towards an aesthetic, both of the look/feel and of interaction of the wearable, unbound by conventional electronics. It allowed us to examine together issues of form, fabrication and interaction through an iterative design driven way. We report the process and the lessons learned through four iterations of designing the wearable material *Flow*.

2 DESIGNING TACTILE MOTION INSTRUCTIONS

HCI researchers have been exploring different approaches to support the learning of physical activities through wearable technologies (wearables) that guide, restrict or notify the body about movement. Although there has been a growing interest in technologies such as electrical muscle stimulation (EMS) [5,14], vibrotactile stimulation has been the most widely explored technology in the context of active learning and guidance. Thus, vibration was considered our starting point.

While there is evidence to support that real-time instructions have the potential to improve the performance of users training physical activities [7,8,11], it is still not well understood how tactile instructions can be employed. Research results in the area are inconclusive about the most efficient and intuitive strategy for the cues, e.g. which metaphor between push or pull represent how the user should interpret the cues. Although it has been suggested that the strategy for its implementation can be a matter of personal preference [2,11], this inconclusiveness can be attributed to the lack of information given by this form of actuation.

Instead of compensating the gap of information with metaphors, we chose to explore how to convey richer information through tactile stimulation. We found inflatable actuators (inflatables) to offer the opportunity for conveying direction by means of pressure to push against the body. The versatility of this form of actuation is particularly interesting for wearables. Inflatables have been implemented in a variety of wearable applications. Those include virtual reality [3], sports such as skiing and snowboarding [15] and as an alternative to vibrotactile stimulation to prevent discomfort and sensory adaptation [10].

3 RESEARCH THROUGH DESIGN PROCESS OF FLOW

Flow is the material outcome of a process comprised of four main iterations (Figure 2). The core of this project was formulated based on first person perspective explorations [12]of vibrotactile stimulation, body movement and of materials on the body (iterations 1 and 2).

We began by exploring how to use the surface of the wearable to conduct the vibration on the body. For that, we created a double layered shirt to insert a boning strip (material used in corsetry

Figure 3: Fencer holding foil and wearing Flow

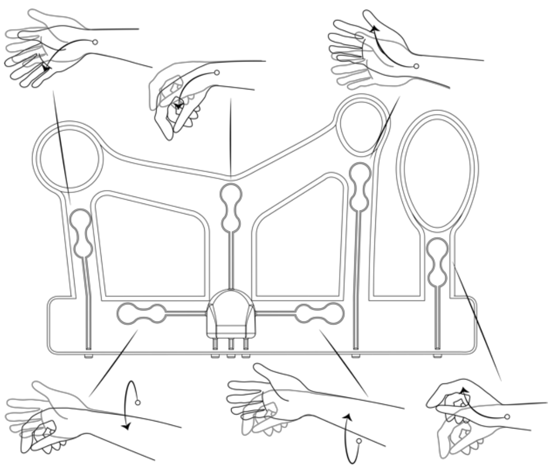


Figure 4: The body movements correspondent to the six cue points of Flow (open)

for support) in varied positions on the torso and the arms. A vibration motor was attached to the end of the strip. Through this prototype, it was possible to experience vibration at different points of the body depending on how one moved. In Iteration 2, we experimented using this technique to specify stimulation paths to cue two directions. This prototype was made by casting a silicone Y shape with tunnels for the inserts. Although the points were distinguishable, we concluded that vibration could not provide directional information without the use of metaphors. On the other hand, these early explorations showed us that it was possible to reduce the number of nodes used by approaching materials as extension of actuators. Thus, we shifted towards focusing on how to provide directional cues by means of silicone-based inflatables. Foil fencing was chosen as an activity to provide the anatomical reference for the development of the prototypes.

The concept of separating movement into the fundamental joint movements of the body [9], inspired us to define six points of actuation to cue the wrist and forearm. The cue points were included progressively into our prototypes. Their position was determined based on experimenting with the materials on the body. Iteration 3 included 5 of the 6 points, embedded into a rubber form factor that served to push the inflation inwards. A user evaluation with this prototype, manually actuated, informed the changes for the final design, Iteration 4 (see section 4 for details).

3.1 The final design of Flow

Designed to cue the fundamental joint movements of the wrist and forearm, Flow (Figure 3) is a wearable entirely made of skin safe silicone (Ecoflex® 00-30 hardness). 3D printed inserts made of polyvinyl alcohol filament (PVA) created the airways and the six inflatable points that correspond to each of the movements (Figure 4). The positions of the air chambers were defined based on anatomical references that a fencing teacher could use to guide students through physical contact. The intention was that the cues would embody the pressure of their touch. As a concept, when implemented in a system, those points would allow communicating how the user should move by separating a fluid movement in joint movements. The sequences of action to be performed would be conveyed by actuating the sequence of the correspondent cues. For the present work, however, we focused in developing how to cue the individual movements. As a demonstrator, the actuation was done through air pumps (NEJE AH0002-4 Mini 0.028A Air) connected to an Arduino Leonardo micro controller and an Adafruit Motor/Stepper/Servo Shield.

4 REFLECTIONS ON THE RESEARCH THROUGH DESIGN PROCESS

Starting from vibrotactile stimulation, our design focus shifted from directional metaphors towards a more literal presentation of direction of movement by pushing against the body by means of inflatables. Through making and reflecting, RtD enabled us to 1) pinpoint limitations of vibration, 2) identify advantages of inflation and 3) construct a proposition of how to transition to inflatables. As the outcome of this process we present four transitions we observed on our development: material as extension of actuators, design for anticipation, expressive stimulation and wearable composition.

Figure 5: Interaction design student evaluating Iteration 3 prototype

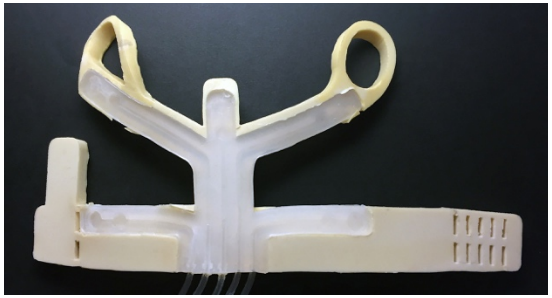


Figure 6: Inner side of iteration 3

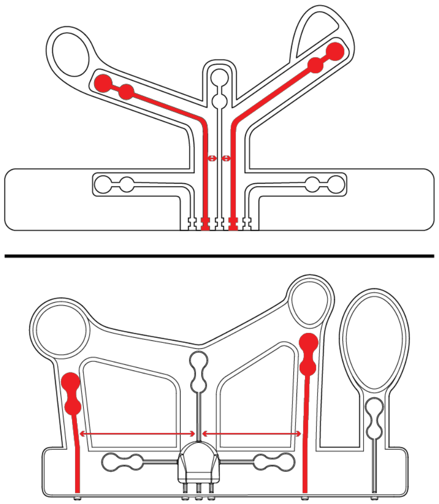


Figure 7: Changes made from iteration 3 to 4 in the distribution of paths

4.1 From multiple nodes to materials as extension of the actuators

Complex tactile motion instructions may require working on larger surfaces of the body or actuating multiple points at once. Typical vibrotactile systems rely on several nodes placed on the body, increasing the complexity of fabrication of the wearable. To address this issue, one of our interests was to use the worn materials as extensions of actuators. For this, our starting point was experimenting with a double layered shirt that allowed for inserting a long boning strip attached to a vibration motor in different positions (iteration 1). With this prototype, it was possible to perceive the actuation on multiple points along the strip through the same vibration motor. The experience depended on the contact of the material and the body during free movement.

Another take away was that the interaction was playful but did not express direction. We then experimented whether defining two opposite stimulation paths would increase the perception of guidance (iteration 2). The experience confirmed the need to move away from vibrotactile stimulation for our purposes. Regardless, it also demonstrated the possibility of using materials as an extension of the actuators. This approach opens up opportunities to integrate technology into wearables from the perspective of the material properties and the surface of the wearable.

4.2 From noise to redundancy seen as anticipation

A cue can be perceived as noise if the message is not clear. In the case of vibrotactile stimulation, repetition is often used to reinforce or compose a cue through one or multiple nodes. However, the use of multiple nodes overcomplicates the cues and the fabrication of the wearable.

To understand the relationship of redundancy and noise for inflatables, we assessed the Iteration 3 prototype with four interaction design master students (Figure 5). The assessment included 1) identifying the cues, 2) rating their clarity and 3) describing what the stimulation felt like. The most significant outcome was that feeling airflow through the paths either reinforced or mislead their perception of the cues. Although the cues were considered relatively clear, scored 7 on average of a scale 1-10, participants often tried to confirm what they felt through vision. The opacity of the rubber made it harder to identify the number and location of the cues (Figure 6).

In iteration 4, changes were made to improve the cues and to support the user in anticipating the behavior from the wearable: 1) the distribution of the paths traced along the length of the areas of the body to be moved (Figure 7). This way, the paths reinforced the cues; 2) the final design was transparent to help the user identify the cue points before use; 3) a lower hardness silicone was used so the inflation would make a more discernible push against the body; 4) instead of pushing the inflation against the body through a hard rubber outside layer, the outside layer of the wearable was made thicker than the inner one.

4.3 From limited to expressive stimulation

Additional information may be communicated via the wearable (e.g. to signal the end of a movement) by exploring and expanding the vocabulary of expression of the actuators. A wide range of vibration patterns, for example, can be created by controlling its frequency, duration and

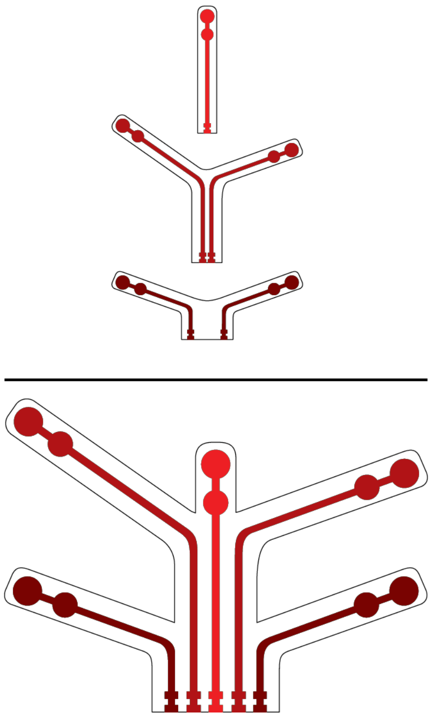


Figure 8: Separate sections of inflatables (top) were used to explore on the body how to compose the inflatable piece used in iteration 3 (bottom)

amplitude. Exposure to this stimulation for a longer period of time, however, can cause discomfort or desensitize the user to the vibration cue [1]. This limits the expressivity of this form of stimulation. Inflatables, on the other hand, offer versatility through shape change.

Exploring this expanded vocabulary was not within the scope of our project. Nonetheless, throughout our process we learned that patterns similar to vibration could be created through inflatables. During the assessment of the Iteration 3 prototype, for instance, a pattern similar to pulsation was created by inflating and deflating the actuators with a syringe. Moreover, we learned through iteration 4 that a constant low airflow from the air pumps used in our prototype could deliver the sensation of vibration on the actuation point. This indicates that inflatable actuators are capable of delivering different kinds of information to the body, appealing to both cognitive and bodily skills. This enables the creation of a wide vocabulary of embodied interaction that may include push to deliver directional cues as well as other concepts like pulsation, tap, tracing and squeeze to deliver other types of information pertinent to a given context of application. In the context of virtual reality, for example, the Force Jacket [3] explored this possibility of using inflatables to create expressions in two modes, force and vibration.

4.4 From composite to wearable composition

To appeal more to bodily skills, we took a hands-on approach of exploring prototypes with our bodies to focus on the detail of the wearable. This process enabled the transition from a stand-alone actuator to a wearable whose structure operates as a material extension of the air pumps.

Although vibration motors are available off the shelf in a wide range of sizes, specifications and form factors, their integration into wearables is still dependent of some form of encapsulation. The interconnections between hard and soft materials are often challenging. Inflatables, on the other hand, are flexible and more easily customizable in size, shape and material (properties).

From our experience with vibrotactile stimulation on Iteration 2, we transitioned towards inflatables aware of the need to investigate how to compose a wearable with all actuation points so they are identifiable. We first worked with them separately (Figure 8). Throughout explorations on the body, the combination of the shapes of the air pockets and paths evolved together with the overall form factor. The resulting aesthetics moves away from the one imposed by electronics or traditional robotics. Rather than trying to match two separate developments, garment and technology, it was possible to deal with functional aspects of actuation and of wearability together.

5 CONCLUSIONS

As the conclusion of a hands-on approach, we proposed a way of dealing with soft wearables to overcome some of the challenges of designing directional cues for the moving body. The result was not just the design outcome but also the knowledge on how to design for motion instructions through inflatable actuation in wearables: 1) integrating technology from the perspective of materials, 2) supporting the user to anticipate the behavior of the actuation, 3) expanding the vocabulary of expression given by the actuation through modes and 4) dealing with functional aspects of actuation and of wearability together. Our reflections about transitioning between actuation approaches through the exploration of the materials may guide others to shift the complexity of actuation from electronics to the wearable material. The design notions behind Flow could be applied to different physical activities that require focus on movements of the wrist and forearm. To generalize the concept of Flow to other parts of the body and physical activities, future work should investigate interference of contextual aspects (e.g. striking the foil) as well as dynamic aspects of guidance, such as delay of response. Beyond sports, other contexts of application that may benefit from intuitive tactile motion instructions include physical rehabilitation, posture correction (everyday living) and safety at work for heavy physical activities (e.g. forklifters).

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