Exploring aesthetic enhancement of wearable technologies for deaf women

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Exploring Aesthetic Enhancement of Wearable Technologies for Deaf Women

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ABSTRACT

The Quietude project uses making, participation and co-design to collectively imagine a more sustainable, aesthetically enriched future for deaf women, by developing wearables that respond to the women's needs and desires: those that are well known, and those that may be only dimly glimpsed. We present our motivation and process, and describe our first workshop that brought together deaf women, ethicists, makers, designers and technology experts. The workshop led to the design and development of an ecology of jewellery products: fashionable accessories that enhance the experience of deaf women by translating sounds into vibration, light patterns and shape change. We reflect on the opportunities and challenges of developing aesthetically rich wearables for deaf women, using experimental participatory design methods, and the value of considering disability as an opportunity for wearables design, rather than as an issue that needs to be addressed or solved.

Author Keywords

Disability aesthetics; co-design; research through design; material cultures; wearables.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

A common, if problematic, view of disability is as a lack or insufficiency to overcome [82]. As a result, many well-meaning technology experts seek to "solve" the "problem of disability" through tech fixes by (re)making disabled bodies [9]. The resulting technologies may conform well to medical needs, but they often neglect complex aesthetic needs of the individual. Quietude [69] takes a different approach. Rather than seeing disability as a problem, the Quietude project values disability as a form of human variation. We recognise that disability is in part medically constructed, in part

socially constructed, and that the economy between social representations and the body is not unidirectional or non-existent, but reciprocal and thus complexly embodied [63]. We agree with feminist philosophers that knowledge is socially situated and adheres in embodiment, that identities are socially constructed (and thus embodied), and that some bodies—in particular disabled bodies—are excluded by dominant social ideologies [33, 34, 63]. We also recognise that, as a result, people in marginal social positions, such as deaf persons in hearing-oriented contexts, "enjoy an epistemological privilege that allows them to theorise society differently from those in dominant social locations" [33, 34, 63]. We therefore consider disability as a source of valuable perspectives from which to design—not only for disabled persons, but for everyone. Grounding our work thus, in theories of complex embodiment, demands mindful attention to the complex embodied expertise of the people we are designing for. It requires we find effective ways of surfacing divergent, perspectives, while being attentive to how radically these perspectives may differ from our own.

Our team includes deaf people—mostly women—from a range of professional backgrounds and with varying levels of deafness, as well as ethicists, designers, makers and technology experts. Our process draws from technology, fashion, material cultures and crafting, and uses a curated form of thinking-through-making, supported by a participatory, applied action-reflection approach to Research through Design [42] to surface the deaf collaborators' needs and desires. We adapt these generative research methods [60] to foreground ethics, and embodied and material approaches to aesthetics, in the specific context of working with deaf people. Our aim is to surface individual perspectives, and collectively imagine more sustainable, aesthetically enriched futures for deaf women, in a world which is strongly oriented towards sound. As we will discuss, this process is affording deep reflection, and diverse responses to our deaf collaborators' needs and desires: those that are well known, and those that may be only dimly glimpsed.

In this article, we discuss our first workshop, and the ways that we use participatory Research through Design and thinking-through-making to bring the diverse team members together. We present our workshop findings, system design and first prototypes, and reflect on the opportunities and challenges of developing aesthetically rich wearables with and for deaf women. We then highlight challenges and

opportunities of designing for aesthetic enrichment in the context of deaf women. In doing so, we reflect on how working in specific, demanding contexts of use can enrich wearables research for any context. Our contribution, thus, goes beyond the context of wearables development for deaf women, to the development of wearables more broadly.

FASHIONING COMPLEX EMBODIMENT

Culture vs. engineering:

Wearable elements—clothing, modules and devices—can support development of novel, technologically augmented clothing and accessories. Clothing and accessories perform important physical, social and psychological functions [6], among them providing protection and concealment, supporting communication and individualistic expression, and signifying status or affiliation [2]. Fashion designers consciously engage with these functions to produce fashionable and philosophical meanings in tangible form that wearers navigate and adapt to their personal skills, preferences and changing circumstances [7].

While wearables have the potential to significantly enhance such functions, and also define new ones [58, 64], developers of wearables seem to struggle with what may seem competing demands from culture and engineering and typically pay scant attention to idiosyncratic needs of potential wearers—for well-justified economic and technological reasons. As a result, on one hand, we find a wealth of projects that explore the cultural, aesthetic and poetic potential of wearables that typically remain outside the market: in museums, galleries, and design spaces, operating as tantalising thought provocations, unable to be worn, to be adapted to personal contexts, or to impact everyday lives through use. On the other hand, we find increasingly sophisticated technical offerings for use in health, medicine, sports, fitness and safety. These wearables often address a specific need and are brought to market with minimal consideration of cultural meaning, social impact or design aesthetics. The results—particularly in medical and safety contexts—can be out of sync with public opinion and the cultural currency of fashion and dress.

Merging cultural understandings of how and why people engage with dress, and technology-oriented understandings of what might be important to focus on when developing wearables, can bring benefit. Doing so remains a challenge, a challenge that fashion theory can help us to think about.

Fashioning relevance:

Fashion theory foregrounds social and cultural aspects of dress, recognising it as a crucial aspect of embodiment, that shapes the self physically and psychologically [20, 66]. As Entwistle argues [19], the body is a socially constructed phenomenon—at once a physical body, consisting of its biological materials, and a part of culture, influenced by gender, society *and* circumstance. There is thus no single 'body' that is everywhere and always the same that we can design for [2]. This perspective echoes complex theories of

embodiment and disability theory [62, 63, 82]. Additionally, the ways that any person wears clothes shifts and adapts in response to both material and cultural concerns [2]. Such needs vary both between and inside cultures, depending on social expectations encountered in daily life, and personal choices that can shift from person to person as well as from moment to moment. Wearables do not typically afford such 'shifting'—between persons, bodies, contexts, circumstances, cultures, or moods.

Dress relates people to each other [8]. The act of dressing is an embodied activity that links society, culture, social interactions and daily lives. It is an intimate expression of the experience and presentation of the self [56] that cannot be isolated from the moving body it adorns [19]. The personal and social entanglement of dressing is a largely overlooked design opportunity for wearables. Our process holds attention to the associated entanglement and shifting.

Embodying felt experience:

A major challenge for design that sits close to the body is to work with relationships between bodies, materials and contexts [68]. As discussed in [86]: "Embodied Design" responds to this challenge. It enlivens design and research potential by leveraging all of a person's senses in an emergent design space. Embodied Design draws on phenomenology [35, 36, 51] and related theoretical frameworks such as pragmatist aesthetics [14, 65], embodied cognition [75] and embodied, embedded and enacted minds [10, 11, 25, 26, 27, 46]. It covers a diversity of methods, approaches, ontological registers, and changing definitions and—like phenomenology—can be considered a "style of thinking" rather than a doctrine or method; a "re-learning to look at the world" that favours reflective attentiveness to "lived experience" [51]. Unlike Embodied Interaction [16], embodied design brings a phenomenologically informed focus to the full cycle of design research and development: ideation, speculation, engagement and analysis, as well as interaction. It thus moves beyond Dourish's proposition for embodied interaction [16, 17] to include methods designed to ensure the perspective of the mobile body [48, 50, 73, 83], to address the mundane and the intimate, to inspire new forms of interactions and new forms of design—for the actual corporeal, pulsating, live, felt body (c.f.[39]). When applied to wearables, Embodied Design connects intimately to theories of fashion and dress, and complex theories of embodiment. It can thus be leveraged to understand how to socially embed wearables in ways that support different wearers' highly personal, and shifting, needs and desires.

WEARABLE TECHNOLOGIES FOR DEAF PEOPLE

In this section, we focus on related research in the area of interactive jewellery, and accessories and wearables for deaf persons—the focus of the Quietude project.

Interactive jewellery

Contemporary jewellery and accessories are diverse in their expression (c.f. [12]), yet this potential remains relatively underexplored within interaction design. Strong

foundational research has been undertaken by Sarah Kettley [45] and Jayne Wallace [78], who both argued a decade ago for the potential of interactive capabilities to enhance the capacity of jewellery as "particular, intimate form[s] of object" that play "a strong role within our developing sense of self and within meaningful and personal human relationships" [78]. We now see increasing work in this area, for example, Tsaknaki and Fernaeus who, like Kettley and Wallace, foreground craft in their research [21, 70, 71, 72].

Outside of academic research contexts, Melbourne-based jewellery designer Leah Heiss [37] therapeutically augments medical jewellery using nanotechnologies and micro-electronics. Her work is powerfully oriented towards aesthetics when designing wearable health products. Examples include jewellery for pain-free delivery of diabetes medication, a wearable cardiac monitor, and "emergency jewellery" to identify the wearer, and their allergies in a medical crisis [37]. In March 2018, after "many years" including collaboration with 25 hearing-aid users, deep collaboration between design, engineering, signal processing, manufacturing and audiology, and 130 3D-printed prototypes, Barney Saunders Hears launched Facett, a hearing-aid developed by Heiss [5, 38]. The time and effort required to develop this product reflects how challenging it can be to develop precious, bespoke items for use close to the skin. As Heiss writes: Facett is an emotional technology that is precious rather than medical in its aesthetic. It thus helps shift hearing-aids from *dis*ability to *desir*ability [38]. See also Tsaknaki et al. for discussions of preciousness and the challenge of 'hybrid crafting' in Interaction Design.

Accessories and wearables for deaf persons
If we look beyond hearing assistive devices to other kinds of wearables designed for deaf persons, we find a number of projects that map sound to vibration. Neosensory's Versatile Extra-Sensory Transducer (VEST) [18, 53], for example, maps sound onto the torso to leverage human pattern recognition abilities. While functionally effective, VEST's aesthetic is quite particular and, we suggest, limited in terms of its appeal and thus the contexts in which it might be worn. A more sophisticated embodiment is Cute Circuit's Sound-Shirt [13], which transmits orchestral sound to the body in real time, mapping instrument groups to body locations to afford a fully immersive experience. VEST and Sound-Suit use lights to signal functioning, rendering their use highly performative. As we discuss later, such performativity may or may not be interesting for a deaf person.

Other vibrating accessories for deaf people include Vibrohear [77], a bracelet that signals the presence and volume of sound; Music for Deaf People [55], a concept collar from the German designer Frederik Podzuweit that converts sound into vibration; and Vibering Sensor [76], a concept watch, coupled with two rings, that vibrate according to the distance and position of a sound. Of these examples, only Music for Deaf People makes a tentative move beyond a conservative embodiment of jewellery; and

only Vibrohear has attempted the move from prototype to product.

In the realm of products, Patti + Ricky is a website that brings together a range of 'stylish and functional designer products for individuals with 'disAbilities' [54]. The products they carry include hearing aid jewellery, casts and slings, fashionable clothing made to fit wheelchair users, and more. The site proclaims the need for 'stylish empowerment' for people with disabilities, and provides a wide range of products for men, women and children. At present, no products they sell afford technologically supported, *smart* interactions.

Wearable gadgets
An emerging trend of smart jewellery and accessories is to transition existing gadgets into fashionable body-wear. Intel's MICA, for example, like many such gadgets, supports interaction through a touch screen with predefined visual or tactile feedback [52]. Juhlin and Wang argue the need for fashionable perspectives to make such gadgets more appealing [43, 79].

An exception to the screen-based orientation of wearable gadgets is Hsin-Liu Kao et al.'s on-body robot Kino—a kinetic accessory system that "alters the appearance of clothing for aesthetic presentation" [44]. It does this through on garment displacement of small brooch-like robotic modules. Kino affords function-driven applications such as shape-shifting close to the neck of the wearer in the event of an incoming telephone call, or unfolding or refolding a hood in response temperature changes.

This landscape of products demonstrates both lack and opportunity. Bringing attention to the aesthetic needs of individuals is important for wearables. Drawing from fashion theory to support this engagement is coherent. Doing so with an orientation towards body diversity is critical.

QUIETUDE: ENRICHING THE QUALITY OF SILENCE IN A HEARING-ORIENTED WORLD
Quietude has at its core the desire to imagine a more sustainable, aesthetically enriched future for deaf women by developing wearables that respond to the women's needs and desires: those that are well known, and those that may be dimly glimpsed. In this section, we present our motivation and process, our first workshop, which had as its aim to connect the diverse collaborators and illicit inspiration for the system design and prototypes. From this basis, we reflect on opportunities and challenges of developing aesthetically rich wearables, taking into account body diversity.

Motivation
Quietude is funded within the H2020 EU Research Programme, WEAR Sustain [81], which aims to stimulate awareness of ethical issues that can arise when wearable technologies collect users' personal (physiological) data. In line with the purpose of the program, *Quietude* envisions a more sustainable role of users to (1) better understand and articulate their rights to access, own, explore, and use their

body data; and (2) play an active role in interpreting this data; both of which are, presently, extremely challenging.

Our team includes deaf women from a range of professional backgrounds and with varying levels of deafness, ethicists, makers, designers and technology experts. The group has been assembled specifically to develop aesthetically sophisticated objects of desire—iconic pieces that draw inspiration from deaf women's personal experiences, the innate sensuality of the body, and the power of accessories to embody desires; acknowledging that personal expression, visibility and discretion can be complexly intertwined and deeply meaningful—and bring these products to market. Crucially, *Quietude* leverages the expertise of deaf experts alongside that of the other team members—as equal contributors driving the final outcome.

The project takes inspiration from the seminal research of Frank Geldard [30] who studied the expressivity and communication capabilities of the body's surface.

The skin is a good break-in sense: cutaneous sensations, especially if aroused in unusual patterns, are highly attention-demanding. [30].

Geldard envisioned the possibility to define a new tactile language *Vibratese*, using tactile stimulation to present complex information to humans. His vision connects to the work of Paul Bach-y-Rita, who developed vibro-tactile displays to enable blind people, for example, to remap their brains and 'see', or people with damaged vestibular systems to 'rewire' their brains and thus develop a 'replacement vestibular' system so they could balance again [1, 15]. Bach-y-Rita focused on the pragmatic possibilities of vibro-tactile language, whereas Geldard's vision incorporates the sensual and poetic aspects. Inspired by their work, we explore the potential of kinetic and tactile stimulation on the body surface to design aesthetically enriched, fashionable accessories for awareness, safety and social sustainability of deaf women in everyday life contexts.

Methodology

In *Quietude,* we adapt thinking-through-making, participatory Research through Design and Co-design to the specific context of working with deaf women.

Thinking-through-making emerged out of Gaver et al's work in *Cultural Probes* [29]. Cultural Probes were developed to give designers access to the thinking and desires of a specific set of users in order to inspire design processes. Probes typically consist of activity prompts sent out to participants, who interpret the activities however they wish and send their responses back to the designers. Our reinterpretation of this process uses *thinking-through-making, moving* and *doing* as the basis for enabling real-time situated exchange between designers and others. Like critical making: "materially productive, hands-on work [is] intended to uncover and explore conceptual uncertainties, parse the world in ways that language cannot, and disseminate the results of these explorations through embodied, material forms" [57].

Thinking-through-making also draws on performative approaches, such as the tightly structured instruction sets commonly used in the Fluxus movement [24], reflecting—or reaching towards—the inherent performativity of wearables [83]. These instruction sets enable a designer-facilitator to prompt participants to engage in an embodied thinking process that results in exploratory objects and ideas that serve as props and prompts in physically engaged activities. The whole process assists participants to move from abstract (personal, knowledge-based) embodied exploration into a specific articulated design space in which they can explore idiosyncratic desires in relation to possible futures. *Thinking-through-making* is enacted within the context of— as a form of—participatory Research through Design.

Research through Design (RtD) is a hybrid approach that employs methods and processes from art and design as legitimate modes of inquiry [23]. RtD is commonly used in technology design research to understand the influence of a new technology on how people think, value, feel, and relate [86]. It makes use of designerly activities as a way of approaching messy situations with unclear or even conflicting agendas [28].

By engaging users in creative play with research ideas and techniques, *participatory RtD* shifts the research focus toward the future, instead of the present or the past. It provides opportunities for community engagement in a discourse and allows consideration of the broader ethics of what is proposed, developed or designed. Further, by leveraging embodied thinking-through-making, the first author's approach to RtD generates personal knowledge, as well as knowledge that can contribute to societally relevant design of future outcomes. Foregrounding the participatory in RtD thus enables researchers to co-investigate design possibilities through an embodied engagement with material and form, and prototype emergent material artefacts that generate reflections and responses around emergent ideas. In this applied action-reflection approach, it is not the outcomes that are the focus. Rather, the making serves as a form of negotiation of emergent ideas. This approach is ideal in a team of collaborators who bring divergent perspectives. It assists people to bring into language things that they may not previously have reflected on in explicit ways or tried to articulate to others.

Finally, *Co-design* enables us to support team members who are not deaf or hearing impaired, in understanding the cultural, societal and usage scenarios encountered by deaf women. Co-design affords collective creativity across the span of a design process. It affords the creativity of designers and people not trained in design to work together in the design development process, bringing differing perspectives to bear on creative decision-making [59]. As one of our deaf experts—a psychologist—stressed, hearing people will never understand the desires of deaf people, because they begin from the assumption that hearing is a desired state. Yet, this assumption is often erroneous. Co-design enables us to

Figure 1: 'Feeling Voice' workshop, Day 1: (*l-r*) *not hearing / being heard* discussions → mind-map →body map (Task 2–3)

navigate the tensions of such insurmountable difference, and articulate more precisely and realistically what might be meaningful for deaf people, and which benefits to aim for.

The careful interweaving of these research processes enables us to bring into being previously unarticulated thoughts and desires, as we consider and discuss concrete and tangible actions to afford different experiential outcomes. Following, we describe the first workshop, which brought the team together for the first time and served to promote empathy among participants, to generate inspirational material, and to elicit values, desires, and unmet needs of deaf participants. Co-design activities were planned in the last two days, to consolidate and materialize what emerged in the first sessions.

WORKSHOP 1: 'FEELING VOICE'

Our team—in broad strokes—consists of a fablab group, a design group, an app development team, a group of deaf experts, and a group of ethicists and social sustainability experts who support and work alongside deaf people. These groups are not all discrete. Nonetheless, describing them thus can be helpful to both manage and describe our unfolding process. The social sustainability experts also provide translation services—from deaf-sign to English, the working language of the project.

Our first full project meeting, the 'Feeling Voice' workshop, needed to: (1) establish modes of communication and develop the necessary trust for creative risk-taking among team members, both within and across the different groups; (2) introduce the participatory, RtD and Co-design methods; (3) introduce some technological possibilities we might explore, in particular to collaborators with little or no prior technology experience; and (4) generate inspirational material that the Fab Lab group, design group and app developers might use to make a first, rapid pass at system design and prototyping. The workshop was scheduled to run for 6 Days, as follows:

Day 1 and 2 involved everyone. Day 1 focused on *Feelings*, Day 2, on *Forms*. Days 3–6 involved the Fab Lab and design groups only, including one deaf expert. The app developers worked in tandem. The majority of deaf experts did not

participate days 3–6, though they were originally expected to be present on Day 3.

This planning acknowledged the different development requirements of the different groups, including time needed to reflect and respond to emerging ideas. We provide a more detailed breakdown:

DAY 1 ~ FEELINGS

1. *Introduction*: all team members introduced themselves. Of the four deaf experts, one was a psychologist, one an architect one an educator, and one a communication design undergraduate student who had been working in the fab lab. The communication design student was the only deaf expert who had prior experience with rapid prototyping of novel material forms with interactive capabilities.

2. *Feeling-mapping*: *not hearing / being heard*: working in pairs or groups of three, all team members (deaf and hearing) identify feelings they have about *not hearing* or *being heard*. Each feeling is given a name, the name is written on a post-it note, and the note placed on the wall (Figure 1). As a **mind-map** emerges, participants are encouraged to actively group notes and ideas, and identify **keywords**. One particularly potent example was the phrase: "feeling under water."

3. *Body-feeling* pairings: in new pairs or groups, team members (1) make a crude (self-drawn, A3-sized) body-map; (2) choose feelings from the mind-map created in task 2; (3) write these 'feelings' onto new post-its and place them on their **personal body-map**. Choices do not need to follow a particular logic or be coherent with anything done previously. Participants are instructed to follow their instincts no matter how fanciful. Once 'completed', body maps are placed on the wall (Figure 1) and are updated as needed.

4. *Materials introduction*: a wide selection of **materials**, with different characteristics—visual, tactile and behavioural—are arranged on the table. Participants are asked to experiment with how different materials feel and behave, and to try to find the right **material feeling** for the **body/feeling pairings** identified in the previous task.

5. *Technology introduction—vibration:* **a wide selection of technologies**, with different characteristics and interactive
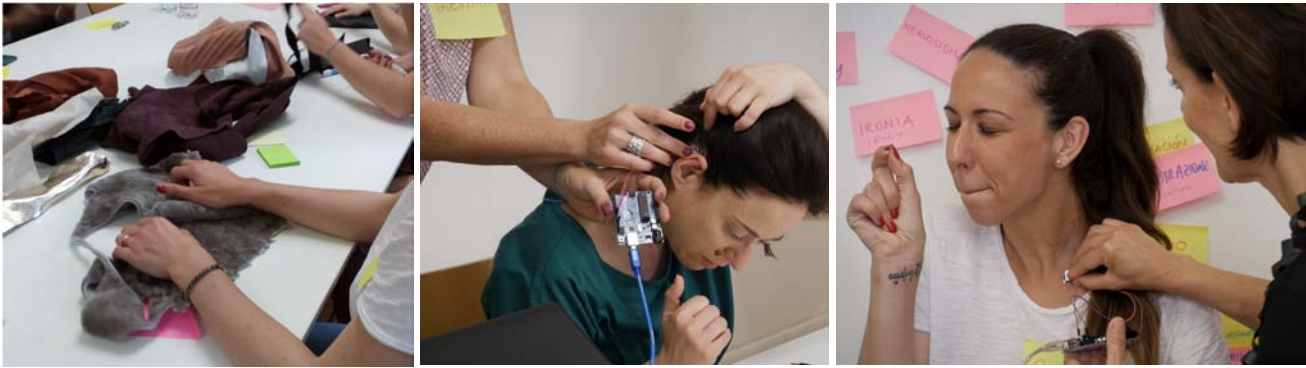
Figure 2: 'Feeling Voice' workshop, Day 1: (*l-r*) Materials, Technologies and Vibration (Tasks 4–6)

attributes, are arranged on the table. Many of them vibrate. The director of the fablab explains different elements. The workshop facilitator dismantles off-the-shelf elements and discusses form-factor and customisation. Participants are encouraged to explore.

6. *Vibration:* Taking inspiration from Vallgårda et al., [74] participants begin experimenting with sexual vibrators as a crude **off-the-shelf technology** that can give direct access to vibration. The incongruity of the sexual vibrator in this context breaks much of the tension around the idea that some at the table hold knowledge or expertise that others lack. We then experiment with **simple vibration circuits** that included a transducer or vibration motor (Figure 2). This process enables us to explore personal sensitivities to vibration, responses and preferences, and discover which parts of the body are best suited to receive or sense vibration input. A range of materials are also used to dampen or attenuate the vibration. This is a first step towards **material customization**, and provides useful information around preferences and impacts in different use-case scenarios. As vibration sensitivities were experimented with and compared, people updated personal body maps as needed. We thus could continually compare the emerging findings.

DAY 2 ~ FORMS

1. *Personal inspiration:* Team members were asked to bring in inspirational images, to share materials, styles and personal desires around the project. Not one team member prepared this task. We thus moved straight to task 2:

2. *Accessorising the Body:* We began with a short presentation to expand how we might be **thinking about accessorising the body**. Images came from fashion, as well as art and performance. The aim was to extend current conceptions of what shapes, forms and materials might be exciting as accessory, and relevant to everyday contexts.

3. *Thinking-through-making*: This task was designed to learn what the deaf women dream of or aspire to—irrespective of whether or not these dreams or aspirations are realistic—by experimenting through form. Following a tightly structured series of tasks, the intention (following [84]) was to bring these desires, including **yet-to-be-imagined desires**, into being.

Following a small mutiny from our deaf collaborators, who were impatient to see outcomes, rather than perform the above task, we engaged in **a lively discussion** of what is important for them: why they are participating in the project, and what they hope we might achieve together. Shortly after starting on day 2, we had discovered that four of the five deaf experts could not be present Day 3, so the benefit of working instinctively—without clearly articulated goals, expressed in advance—seemed frustrating to team members who had little prior experience with generative design processes.

In lieu of task 3, we followed our discussion with an **embodied exploration through materiality**—holding materials and technologies to the body, simulating movement and vibration, testing very rough approximations of what people were trying to express, in order to come to shared understandings of those expressions. This approach, done in a quick and rudimentary way, echoes Tomico's Material Props in Context Method (described in [68]).

At the end of the day, the first author, workshop facilitator, gave a public presentation about her research, during which she showed outcomes from previous *thinking-through-making* workshops. A number of deaf experts subsequently expressed disappointment that we had not undertaken activity 3. We will elaborate our insights in the discussion.

DAY 3 ~ CONCEPT DESIGN

The fablab and design groups formed two mixed groups. Only one deaf expert was present. She collaborated with both groups, so that each group could encompass the full range of expertise of the *Quietude* team. In these groups, we **brainstormed material possibilities** for different use-case scenarios, using materials and technologies at hand, and generated ideas using interim outcomes from Day 1 and 2.

DAY 4–5 ~ PROTOTYPING:

To develop a suite of prototypes, we revisited the different tech options we experimented with on Day 1, and expanded or shifted our ideas in response to the findings from Day 2. Further, we conducted a **lo-fi prototyping session** (Figure 3), using paper, cardboard and simple fabrics, to enable us to explore possibilities without being constrained by technical limitations. The emergent expertise enabled us to map out the accessory space.

Figure 3: 'Feeling Voice' workshop: (*l-r*) Day 3: Concept brainstorming; Day 4–5: Lo-fi prototyping

We also drew directly from the Day 1 **body maps,** making new maps that complemented, and could be compared to, the previous findings. The aim was to consider the different aesthetics that might come into play, without being constrained by material or technical realities. This approach has proven its value in prior research [85].

*D*AY 6 ~ TESTING, CONSOLIDATING, REFLECTING: To complete the workshop, we tested and discussed the emerging prototypes—a suite of accessories inspired equally by feelings of being underwater and the needs of our deaf collaborators that emerged during Day 1 and 2, and during reflections.

Throughout the workshop, our design research structures were intentionally fluid, to support a reflective conversation with materials and resources in an ongoing and iterative process [61]. This process involved all of the collaborators and enabled us to support highly aesthetic outcomes.

FROM WORKSHOP TO ACCESSORIES
In this section, we discuss how our workshop findings guided the design of a first suite of accessories.

On Day 1, visibility and invisibility appeared as key words on post-it notes and were placed on the body maps close to the head, face and chest. One deaf expert explained that when people talk to each other they typically focus on the eyes and face of the other person. When focused thus it can be difficult, if not impossible, to realise that the other person is deaf.

Our deaf experts highlighted this invisibility of deafness as both a social and a safety issue, suggesting a counter-trend design compared to that of modern hearing aids. Non-surgically implanted hearing devices sit behind the ear or in the ear. They vary in size, power and circuitry, as well as positioning. Those that hang behind the ear are connected to the outer ear bowl—the concha—by a tube or wire; in-ear devices sit inside the concha (and are typically custom fitted). All hearing aids are designed to be as discreet as possible, with some sitting deep inside the ear canal, virtually invisible.

We learned that this effective invisibility of deafness can lead to challenges in interactions. In social situations, hearing people can forget to attend to deaf people's needs and inadvertently exclude them; in busy public places such as transit centres, the invisibility of deafness can be lead to misunderstandings and missed connections. Our deaf collaborators expressed a desire for an elegant and dignified—even beautiful—response to this issue.

Also on Day 1, our deaf experts showed a wide range of sensitivity to vibration. Some identified the neck area as the most sensitive to vibration, others the shoulder or scapula. Still others considered the wrist and forearm to be ideal parts of the body to enact vibrations and micro-movements. It became clear that being able to choose where and how a vibration plays out on the body through an accessory is crucial. As is being able to turn a vibrating accessory on or off. As our deaf architect noted after experimenting with vibrations on the body:

This day made me reflect on the importance of the link between vibration and information. For example: in any given context, it is important to understand the direction relative to the information the vibration is providing me with, also the quality of the vibration, its frequency or the point of contact with specific parts of the body. Above all it is essential to be able to exercise control over such vibration because getting continuous vibration produces disorientation and annoyance. So, it is necessary to be able to decide to turn it off or not use at all. That means I need my freedom.

On Day 2, one of the designers proposed a necklace that expressively enacts sounds, translating them into vibrations and physical expression. This idea was responded to enthusiastically by the deaf experts. We therefore conducted targeted *Material Props on the Body*–style experiments to clarify some design elements, to inform our thinking around the style of such an element.

On Day 3 the team reflected further on the issue of safety, which came up on Day 1. Sounds from the side or behind that require a quick response can go unnoticed by a deaf

Figure 4: *Quietude,* **TRL3 prototype accessories: (*l-r*) Hairpin, Arm Band, Brooch-set, Necklace and App.**

person, and the impact, whether the person is alone or with others, can be devastating. From this reflection, a concept was developed for fashion accessories that are both beautiful and functional, that warn the wearer of alarms or other meaningful sounds. Our deaf collaborators highlighted the importance of a range of meaningful sounds including both personal sounds (e.g. their pet, doorbell, name, etc..) and public notifications, such as alarms, airport announcements, police whistles, and more.

We discussed the possibility of "translating" such sounds into vibrations or subtle movements as a form of alert. Our deaf collaborators found this possibility intriguing. They suggested that, in addition to signalling meaningful sounds, the accessories might also reflect ambient qualities of an environment. Further, they discussed use cases where a deaf person is unaware of noises they produce themselves, such as in a library, walking on a wooden floor with heels. Vibrating and shape change accessories were identified as a helpful support in such situations, as they could signal inadvertent noises in a fun, fashionable and elegant way.

On Day 4 and 5 a mixed group of deaf and hearing collaborators built a fascinator of leather twigs attached to a hair clip (Figure 4, left) to signal deafness to others and also critical sound events to the wearer. The pin includes an Arduino and a microphone. The twigs move in response to ambient sounds. Their movement is clearly visible and can be felt through the cranium. The prototype was considered a witty, elegant and functional accessory when tested.

A SUITE OF ACCESSORIES

The team thus designed and developed a modular suite of accessories that can be assembled to create different pieces of jewellery, such as hairpins, armbands, and necklaces (Figure 4). Being modular, the accessories can be configured in a variety of forms related to external (visual) aesthetic and perceptive functionality. This modularity satisfies the need for personalisation that came up repeatedly during the workshop: the need to express an individual sense of style and identity, and to acknowledge personal preferences and sensitivities to vibration.

The design approach was conducted using an adapted fashion design methodology (c.f. [4]) which included development of a mood board [32] (Figure 5) to give visual form to the different sensitivities and styles that emerged during the *thinking-through-making* act on Day 2. The accessories thus have a strong visual and material aesthetic.

The modules resemble sea anemones, algae and bubbles; the palette of colours reflects images of sand, deep ocean and coral. The colour palette and forms are inspired by the Day 1 keyword: *feeling under water*, which was proposed by a hearing collaborator, and enthusiastically approved by the deaf collaborators. The notion was used to describe a hushed feeling of the perception of sound. The different elements are made using leather, which adapts well to the body, being soft, comfortable and pleasant to wear, and well adapted to expressive kinetic properties. The modules contain functional and decorative elements that move, vibrate or emit light. The necklace leverages three-dimensional shape-change and will become increasingly sophisticated in this regard in coming iterations (following [49]). These kinetic features are used to signal deafness to others, as well as critical sound events to the wearer. They thus stimulate responsible and responsive behaviour: dual functionality our deaf experts repeatedly requested.

While these artefacts remain first pass prototypes, the accessories are stylish and expressive, and have been well received by our deaf experts and others in public events like the 2017 Florence Biennale of Contemporary Art, where a more advanced jewellery collection was exhibited [22].

System development

The jewellery system is composed of a suite of electronic boards embedded in the accessories. The boards are equipped with microphones, processing units and actuators. The electronics are connected to a smartphone through a Bluetooth personal wireless network, to enable users to manage and personalize sound recording and haptic feedback. The embedded electronics translate different sonic qualities (basically low, medium and high frequencies) of the

Figure 5. Quietude mood board. Courtesy Michele Tittarelli, Glitch Factory s.r.l.

ambient environment to the wearer. Our deaf experts explained that hearing impaired people may detect some sound frequencies and be totally deaf to others. The accessories reflect a need to perceive sound quality by mapping movement, vibration and light to detected sound frequencies. The embedded servos expressively enact live or recorded sounds, translating them into movement and physical expression. These kinetic properties are tuned to dynamically represent sonic qualities of environmental sounds. The behaviour of these and other actuators (such as the vibrators, for example) can be fine-tuned to achieve a comfortable, expressive, informative and refined, material choreography, adjusted to personal mood or circumstance.

A smart phone app works with the accessories, allowing personalisation of both input and output, and the construction of a personal library of sounds that can be monitored for, and replayed on demand through the accessories. As our experts explained during the workshop, deaf people commonly use apps to assist them in everyday life. Such apps range from video messaging apps (c.f. [31]), apps that stream live music lyrics (c.f. [67]), instant video-relay apps designed, for example, for British Sign Language users (c.f. [41]), and navigation apps (c.f. [80]). As app use is popular in the deaf community, the idea of using an app to control the accessories was readily embraced by our deaf experts.

To construct a personal library of sounds, the app allows recording and naming of sounds (my dog, the doorbell, my name etc.). These sounds are "translated" into vibrations, light patterns or subtle movements of the accessories to advise the wearer when they occur. Preferences related to kinetics and the quality of vibrations can be set and fine-tuned through the app for different contexts, moods and bodily sensitivities. In this way, the real-time feedback provided on the body, through the app, supports the freedom our deaf architect expressed as so crucial.

The app includes a control panel for managing sensor precision and the quality of the haptic feedback. Parameters such as vibration strength, on-off, as well as aspects of sound recording can be set up through a minimal interface, and immediately fed back onto the body through the accessories. The wearer can thus experiment with the quality of vibration, light and movement of the accessories in real time, and adjust them—personalise them—to suit their embodied preferences. Furthermore, sound recording and tagging functionality enables users to record, tag and store preferred sounds in the library, which is held locally on the phone. This is a key feature of the system since stored sounds are used to map an incoming sound (acquired from microphones embedded in the accessories), and to trigger the accessories' actuators.

OPPORTUNITIES AND CHALLENGES

In this section, we reflect on the opportunities and challenges of developing aesthetically rich, socially sustaining wearables for deaf women.

First and foremost, communication between our deaf and hearing collaborators was necessarily mediated by sign-language interpreters. Some of our deaf experts were able to speak in English, Italian or Spanish. Some could lip-read, or through the use of their hearing aids, hear. Nonetheless, communication at its most fundamental level was challenging, and needed to be navigated across a number of factors: basic socio-cultural and linguistic differences; differing values, objectives and practices across design, making and engineering; and the fundamentally different cultures of deaf and hearing. So, while our hearing collaborators were all trying to bring their diverse expertise to a deaf context, negotiating the relevance of the expertise to that context required constant attentiveness.

The fact that the first workshop took place in spaces associated with the fablab, further impacted our ability to contribute equally. Curiously, the frustrations that came about by suddenly losing a day's scheduled collaboration may have been one of the greatest gifts in this situation. While our scheduled events did not play out on Day 2, the improvised conversation allowed us to break through some of the barriers that are inevitable in mediated communication, including the power structures that surfaced—despite the best intentions—when a small group of people with different abilities, came into a technology research space with a range of acknowledged experts who are comfortable in this space and with the technologies and techniques at play. In such a situation, the expertise of the individual can easily be overlooked. In *Quietude*, our deaf team members are experts at being deaf, experts at being deaf women, as well as experts at various professional activities that are more or less related to the research. Yet, to design for their experience in a hearing-oriented world, our first step was to force them to collaborate on our terms, in a hearing-oriented collaborative set-up.

Our experiences prompt the question: How can Co-design be extended to upstream participation from all stakeholders in meaningful ways within the innovation process, yet enable team members to fully leverage textile and technical expertise? While we do not have the answers to this question, our next steps are clear.

Future Steps

Moving forward, we will enter into the deaf women's world to further our collaboration with a, hopefully more balanced (or more equitably unbalanced) hierarchy. After the workshop, two additional suites of prototypes were developed and fully integrated with electronics. These will be used to experiment the qualities of movement, vibration and light.

Participatory RtD will take several forms, moving forward. In addition to the 'Feeling Voice' workshop described here, other participatory and co-design sessions and testing sessions have been organised to allow deaf women to wear the accessories. These sessions enable us to test functionality on many levels, assessing how they feel and perform for the

wearer, as well as how their performance is perceived (or not) by the viewer or interlocutor. The emerging prototypes are thus being exposed to the scrutiny of their intended consumer base, and the broader communities that may be impacted by their use.

We will investigate additional ways that *thinking-through-making* might be introduced to the deaf community. When our deaf experts expressed disappointment that they had been unable to experiment with this technique, they were responding to two aspects in particular: (1) the outcomes, like many forms of intermediary knowledge [40], and like responses to cultural probes [29], can be wild and inspirational, but they are often sitting in the adjacent possible—barely out of reach; sufficiently close that they support the bringing into being of potential and viable futures; and (2) *thinking-through-making* operates in an extra-discursive space—for the most part beyond language. Issues of language thus recede into the background as participants explore yet-to-be-articulated thoughts through embodied engagement with material and form. Both aspects show promise when trying to bring into being new forms of accessories, in a team that has no clear foundation from which to communicate as equals. We hope this technique will help us make our way forward to new ways of enacting participatory Research through Design in a Co-design process such as that which we set up in *Quietude*.

CONCLUSION

This paper presents an ongoing research on wearables designed for deaf women. We discussed specific needs that emerged in a participatory RtD workshop, as well as early, experience-able prototypes of smart accessories, and challenges and opportunities that arose from our working process.

Designing wearables for individuals who are considered by more body-typical people as having impairments, should not be limited to functional services that reflect the assumptions of those who are body typical (in our case hearing). Rather, we suggest engaging experts in the articulation and development of products that reflect their idiosyncratic, personal, aesthetic needs. We are certainly not the first to make such a suggestion [47], but hope our case adds a powerful voice to the discussion.

To a large extent, disability is socially constructed [81], and to a certain extent contextual. A deaf person may not hear a crucial event without support; at the same time, a hearing person may find it extremely difficult to focus when bombarded by background noise. One cannot assume that being able to hear is always preferable. Indeed, one of our deaf experts said that she often chooses to turn her hearing aid off, as she often prefers being deaf to hearing, even if hearing may be more practical in many situations.

In our approach to designing for and with deaf women, we lean on complex embodiment theory [63] and fashion theory. We recognise that *the body* is a socially constructed phenomenon—at once a physical body, consisting of its biological materials, and a part of culture, influenced by gender, society *and* circumstance; that there is no one body that can be designed for, but that each and every body is different. We also recognise that the economy between social representations and the body is not unidirectional or non-existent, but is reciprocal and thus complexly embodied, and its shifting nature needs to be taken into account.

As feminist theory tells us, knowledge is socially situated and adheres in embodiment, identities are socially constructed (and thus embodied), and some bodies—in particular disabled bodies—are excluded by dominant social ideologies [33, 34, 63]. As a result of this exclusion, people in marginal social positions, such as deaf persons in hearing-oriented contexts, "enjoy an epistemological privilege that allows them to theorise society differently from those in dominant social locations" [33, 34, 63]. By working from this viewpoint, we can approach disability as a source of valuable perspectives from which to design—not only for disabled persons, but for everyone.

Designing fashionable accessories with and for deaf women is allowing us to bring mindful attention to the nuanced skills and preferences that diverse individuals bring to dressing, and the meaning that accessorising brings to individual needs and personal style/s. Dress relates people to each other [8]. The act of dressing is an embodied activity that links society, culture, social interactions and daily lives. It is an intimate expression of the experience and presentation of the self [56] that cannot be isolated from the body it adorns [19]. By focusing on the particularities—the challenges and opportunities—of designing with and for deaf women, our contribution is able to go beyond the context of wearables development for deaf women, to the development of wearables more broadly.

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