DiaFit: Designing Customizable Wearables for Type 1 Diabetes Monitoring

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ABSTRACT

Research has highlighted the need for customization of health-related technologies. However, few studies have examined its impact on wearable healthcare devices. We present a co-design study where we learned about people's preferences and ideas for customized glucose monitors. We worked with people who have Type 1 Diabetes and learned about their challenges with current glucose monitors and ways to address them in physical product design. To understand people's perception towards using customizable glucose monitors, we prototyped one simple example toolkit, *DiaFit*, consisting of multiple modular accessories for assembling glucose monitors. We invited participants to try *DiaFit* and learned about their acceptability of customizable glucose monitors. We conclude with preliminary lessons learned about customization as an approach to addressing individual differences in the context of health technologies.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**.

KEYWORDS

wearables, customization, design for health

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1 INTRODUCTION

Type 1 Diabetes (T1D) is a chronic condition in which the pancreas produces little or no insulin and has implications for the overall well-being of an individual [2]. The prevalence of type 1 diabetes (T1D) is increasing worldwide [40]. While there is no cure for T1D, people can manage their condition by monitoring their blood glucose levels using wearable devices such as glucose monitors. The monitors can be a part of the insulin pump or separate devices such as a digital monitor or a smartphone. While such monitoring devices are typically designed to address functional needs, for example, providing useful visualizations of tracked health information, the "social accessibility" needs related to the combination of form and function are under-explored. The monitoring devices do not always meet the subjective needs of the users [21]. For example, commercially available budget glucose monitors such as True Metrix are known to have portability issues. They are bulky, heavy to carry, and can hurt users in scenarios such as when engaged in playing contact sports [19]. Similarly, the audio-based feedback is often either too loud or too subtle, not offering enough level of control to ensure the privacy of use [24]. Due to these challenges, researchers in the area of design for health have suggested facilitating customization by building bespoke solutions [20].

In our work, we explore customization as a modification of the presentation and functionality of a given product [8]. Researchers have highlighted that it is crucial for designers of self-monitoring devices to facilitate the customization of digital and social functionalities (i.e. physical form and aesthetics) to avoid unnecessary workarounds and to meet users' needs and desires for long-term engagement [10]. However, although we understand the potential benefits of offering customization to enhance personal engagement with wearables, we know relatively little about how the strategy works and how it will be perceived by people [13].

Diabetics' behaviours, self-care methods and their experience with wearables such as insulin pens and pumps have been extensively researched (e.g., [1, 5, 19, 31]). There are also several conceptual design ideas suggested for wearable glucose monitors (e.g., [32, 35–37]). However, these ideas are not implemented or studied. Within this space, the primary contribution of our work is in developing an initial understanding of the design and acceptability of customizable glucose monitors.

In this paper, we present a small co-design [29] study which consisted of three parts. We first conducted a brainstorming session with people who are diagnosed with T1D and learned about their challenges with the current glucose monitors. They also developed ideas for glucose monitors that addressed their concerns. Our discussions with them revealed three key design aspects that were important for them to be able to customize: portability, feedback and privacy of use. Informed by that, in the second step, we synthesized the design ideas suggested by the co-designers and built a simple toolkit, *DiaFit*, consisting of accessories and feedback modules that can be assembled together to create varied glucose monitor designs. Lastly, we conducted 30-45 minute evaluation sessions using *DiaFit* and gained insights related to the acceptability and understandability of customizing glucose monitors. We conclude by discussing lessons learned related to people's acceptability towards customization to make room for individual differences and preferences.

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2 RELATED WORK

In this section, we briefly cover studies that have highlighted challenges with glucose monitor uses and efforts related to the customization of diabetes-specific health technologies.

2.1 Challenges with Technology for T1D

Adults with T1D are adopting, carrying, and using devices in varied and individualized ways to suit their everyday lives [20, 28], and demonstrate a need and desire for bespoke and personalized self-care devices [33]. For example, Holubová et al. [11] have suggested that physically active people with T1D tend to conceal that information from others and could benefit from a technology that would not be an obstacle during physical activity and would not call attention to itself. Other studies, such as the one by Riddell et al. [25] and Messer et al. [17] have shown that their participants indicated that the monitors interfered with sports and outdoor play. Issues such as the size and the weight of the devices, the possibility of dislodging the device and difficulty with monitoring the screen were a few of the challenges experienced while playing sports. Glucose monitors are also used by people to track hypoglycemia or hyperglycemia [12, 34], and for that it is important that the monitoring is reliable and provides sufficient feedback. However, due to insufficient control over feedback mechanisms, people are compelled to deliberately take wrong actions such as silencing alerts [24]. Another issue faced by diabetics is the stigma from their communities and their workplaces [16]. Perceived stigma causes self-consciousness [22, 27], and as a result people often attempt to hide their devices [21]. However, the companion monitors are typically big and bulky and difficult to hide under clothes [39]. The use of monitors also leads to social worries such as the alarm ringing at inconvenient times and creating a sense of being different [4, 24, 39]. Some users may also experience altered perceptions of body image [26] and therefore attempt to hide their devices.

Our work builds on these projects and explores how customization of glucose monitors may alleviate people's concerns and address their needs. Our preliminary brainstorming study gained further insights into these challenges and gathered feedback in terms of design ideas to address the challenges.

2.2 Customizable Technologies for T1D

Activities such as hacking, tinkering, repairing and crafting are growing in popularity [3] and serve as pathways for designing, customizing and manufacturing technologies for T1D. For example, at the lower fidelity end, people create cases for carrying T1D devices [6] and free style stickers [7] for their glucose meters. At the higher fidelity end, DIY groups such as Nightscout have modified continuous glucose monitors (CGMs) to upload data to "CGM in the Cloud" and communicate with other devices such as smartphones and smartwatches [38]. There have also been moves to use CGMs and insulin pumps in conjunction with programmable devices such as Raspberry Pi to develop more advanced T1D technologies [15].

Our work builds on these efforts from the community and discusses customization ideas for addressing portability, feedback and privacy needs by allowing people to create varied monitor configurations. Our vision of leveraging modularity in design could allow people to configure form and feedback and evolve it over time based on changing needs and developments in technology.

3 INTERVIEW AND BRAINSTORMING

We conducted interview and brainstorming sessions to gain insights into how people with T1D envisioned their monitors should look and function. The session consisted of two parts. First, participants engaged in a semi-structured interview (20 minutes) in which we discussed their past and current experiences using T1D devices in everyday life. Second, participants were invited to take part in a brainstorming session (30 minutes) based on the PICTIVE method [18, 30], and they created sketches and models either by altering existing researcher-created sketches and 3D models or by creating new ones (Figure 1a). Using thematic analysis [9] we qualitatively analyzed the interview responses and generated artifacts (sketches and models, Figures 1b-d) to identify high-level themes (e.g., need for multi-modal feedback mechanisms and varied monitor sizes) that can inform the design of customizable glucose monitors. Five volunteer adult participants (A), ages 31-56 years (one male, four female) took part in these sessions and had 1 (two participants), 2, 15, and 39 years of experience with T1D.

3.1 Brainstorming Results

Three main themes emerged from analyzing the interview responses and the artifacts created by our participants: portability, feedback mechanism, and privacy of use. From these, we inferred the main design goals for prototyping future technologies to support customization of physical health devices.

3.1.1 Portability. We noted that although all participants knew that they should carry their monitors with them at all times, they did not do so when engaging in certain activities such as going to the gym or gardening. Similar to past findings [17, 25], the participants mentioned several problems with carrying a monitor. For example, although A5 uses her smartphone as a monitor, she prefers not to carry it because she does not want to be disturbed while working out. A5 also added that she did not carry her monitor with her during gardening since the Bluetooth connection would typically be lost and therefore the device did not provide the necessary feedback.

To address issues with portability participants suggested various ideas for wearable monitors that could be worn on different parts of the body (**Design Goal 1**): most common was the wrist (5 of 5), the second was the ear (3 of 5), and third was on a finger (3 of 5). All suggested designs were attached to or worn on the body, and not carried in the hand. Most of the participants designed prototypes with non-traditional forms such as rings, bracelets, and necklaces. Participants also suggested devices that could adapt to varying contexts, such as making something simply functional or more ornamental depending on the occasion. Some example ideas suggested by our participants are shown in Figure 1b-d. These devices were considered less obtrusive because they are slimmer, can be concealed under clothing, offer flexibility in placement on the body, and draw less attention.

3.1.2 Feedback. Participants told us that they check the monitors whenever they feel the need. However, these feelings alone are not always reliable and, therefore, some form of alerting feedback is

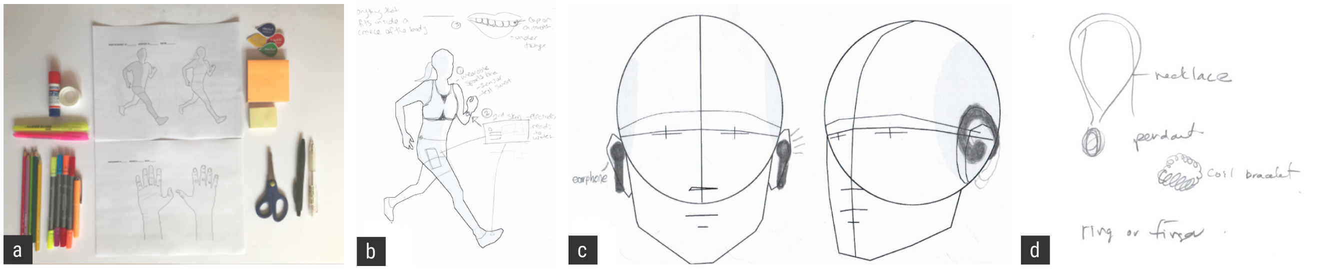

Figure 1: (a) Pictive materials used by participants to create sketches and 3D design ideas for glucose monitors. (b,c,d) Several design ideas sketched by participants showing monitors that can become part of clothing and accessories such as shoes, earphones, necklace, bracelets and rings.

necessary for glucose monitoring systems. Currently, visual and audio feedback are the two main channels used in commercial products and apps. Participants said that if they rely on the visual channel solely they might miss crucial information, and therefore also need audio feedback. However, similar to prior results [4, 24, 39], all participants mentioned the embarrassment caused due to the device beeping at inconvenient times.

A3 mentioned that the device must be within the hearing range, but not so loud as to attract the attention of anyone other than the user. Two other participants mentioned issues such as not hearing the audio feedback sometimes if the device is carried in a pocket or a bag. Three of the participants also complained about erratic and annoying beeping when they do not carry their device in their hand or if the Bluetooth connection is lost. Participants also mentioned that audio feedback might be useful for the kids or elderly who may be distracted while playing or focusing on an activity.

To address issues with feedback mechanism, participants suggested several ideas. The continual use of visual feedback was encouraged by all participants. Currently, visual feedback is provided via visualizations such as numbers, an arrow for trend, and graphs for changes in glucose levels over a period. In addition to these visualizations, A4 suggested using RGB (red, green and blue) LEDs in prototypes of bracelets and rings. She reasoned that different colors can give instant clues as to participants' changing glucose levels. We also gathered other more futuristic designs, such as the one by A2 who envisioned having a wrist wearable with holographic visual feedback. The second most commonly mentioned feedback (and a new addition to the currently available options) was haptic (4 of 5). Participants reasoned that it could provide discreet and personal feedback, and they could feel the vibrations when they did not check the monitor or hear the alarm. Lastly, the third option suggested for providing feedback was audio (3 of 5), usually in the form of an earpiece. Participants mentioned that an earpiece will enable them to receive discrete feedback and they can also continue listening to music or talking on a phone.

Overall, we inferred that receiving information discretely was important to people and they could benefit from having access to different feedback mechanisms which can be used one at a time or combined with others to build a multimodal devices depending on context (**Design Goal 2**).

3.1.3 *Privacy of Use.*

The issue with privacy of use was highlighted by all participants. Privacy in this particular context refers to people's desire to make their device less noticeable and to minimize any risk of social embarrassment. The issues for maintaining privacy stemmed from challenges with portability and feedback discussed previously. For example, participants wanted smaller devices and preferred to have control over how loud the notification sounds would be. While A2 and A5 were fine with their wearable being visible to others, A1, A3 and A4 preferred to hide them in situations where they might be made to feel awkward or self-conscious. All participants mentioned that they did not want to deal with awkward questions or unwelcome comments.

To address such concerns, A1, A3, and A4 wanted their devices to be almost invisible. For example, A1's design ideas included fitting a device into a tooth, the belly button, or between fingers. A1 and A3 also had ideas for skin patches. Both A1 and A4 suggested ideas to embed the device into clothing such as bras and underwear. Three of our participants created design that resembled jewellery, integrating technology into existing objects and rendering them to look like everyday devices.

4 DIAFIT: DESIGN AND IMPLEMENTATION

From our interviews and brainstorming sessions, we inferred that participants wanted more choices in regards to form and feedback mechanisms for glucose monitors. To explore supporting such diverse choices for customization, we built a preliminary simple toolkit, *DiaFit*, that supports modularity in design.

An ideal toolkit that matches the vision of our participants would be a small, easy to assemble, and aesthetically designed device. Its capacity for customization will be extended to digital control over a variety of feedback functions. Ideally, flexible electronic component sizes will offer the end-user an opportunity to design different shapes of electronics holders. The use of fabrication tools such as 3D printers, laser cutters and programmable knitting machines will allow people to produce modules and accessories using a wider selection of materials. Technical support will also be available on an open-source platform.

However, as a work-in-progress and a first step towards gathering design ideas and understanding people's reactions to customizing glucose monitors, we built a simple toolkit, *DiaFit*. This would let our participants develop responses not only through think-aloud

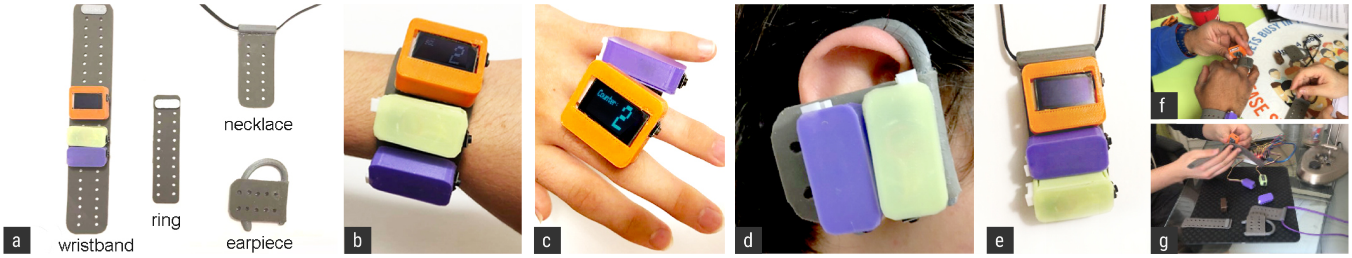

Figure 2: Diafit probe: (a) accessories and feedback modules for building different styles of glucose monitors such as: (b) bracelet monitor, (c) ring monitor, (d) earpiece monitor and (e) necklace monitor. (f,g) Users' interaction with *DiaFit* prototype.

protocols, but also through the act of completing creative tasks by building different configurations of monitors. As shown in Figure 2, *DiaFit* consists of a number of modular pieces that can be assembled together to build a glucose monitor and these pieces are categorized as follows: (a) accessories that enable people to build different types of monitors such as a bracelet, necklace, ring and earpiece (Design Goal 1) and (b) feedback modules that allow communicating glucose levels via audio, visual, and haptic cues (Design Goal 2). Our design is inspired by modular design ideas such as those used by LEGO and FitBit. The feedback modules have strap pins on the back to connect it to the accessories and have small push buttons that enable turning them on/off. *DiaFit* is operated and powered using a microcontroller (Arduino Nano 33 IoT) and a lithium ion polymer battery (3.7V 140mA). While *DiaFit's* current implementation is rough and it does not address the development of sleek and small glucose monitors that our participants desired, we found that it still helped scaffold responses during the preliminary evaluation stage.

5 EVALUATION

The evaluation session aimed to better understand people's responses to creating custom glucose monitors and to gain insights into the types of monitors they would build (Figure 3). We invited five adult (ages 20-52 years) volunteer participants (B) to a 30-45 minute interview and feedback session. Participants had T1D and had been using their T1D devices for a period of 5 to 30 years. After we introduced the modules and accessories, participants interacted with *DiaFit* by building four different configurations of the glucose monitors (Figure 2f-g) based on prompts we provided (such as varied contexts for using the monitor) and shared their thoughts by thinking aloud. All our participants in this session were male. This was not an intentional choice but a chance occurrence due to studies being cancelled during the pandemic.

5.1 Evaluation Results

Overall, all the participants agreed on the importance of customization in the context of T1D. For example, B3 mentioned that he had previous experiences of customizing software for glucose monitors (using Loop, a diabetes management app) and thought that customization is important for diabetics. He said, *"I think many of us would love to have some level of customization around all sorts of little things, from the way it is designed, how it is worn or the type of data they are giving us: visual, audio, phone based, computer based"*. B4 expressed similar sentiments and said, *"It is an important feature for products. It gives flexibility and personal input and makes a product unique"*.

As shown in Figure 3-*left*, regarding the use of different components, four of the five participants felt the wristband could be worn on most occasions with any of the feedback modules. The participants expressed a full variety of preferences for modules which could be combined with the ring but voiced a general concern as to whether the sensors could in the future be scaled down to the size of rings and still remain effective. Three of the five participants felt audio alone would suffice on the earpiece. Lastly, for the necklace, all three feedback modules were considered suitable, but a reservation was expressed that haptic might be problematic because the necklace may not be in constant contact with the skin.

We also asked participants to build versions of the glucose monitor that they might use in varied situational contexts (Figure 3-*right*). For indoor activities, such as in the gym and doing chores at home, the earpiece was a favourite because it kept their hands free and allowed for subtle feedback. For outdoor activities such as walking and cycling, the ring, earpiece, and wristband were all embraced by various participants. Several participants (3 of 5) considered the wristband relatively discreet, easy to check and control, and comfortable enough to wear all day. One participant preferred the ring and necklace and considered them discreet. In contrast, one participant considered the earpiece and the ring too distracting for the workplace. For social settings, the participants expressed preferences for those accessories they considered most discreet, usually the ring or the wristband. By contrast, one participant saw exposing his device as a possible advantage as he welcomed any technology which prompted discussion in the diabetic community.

We asked participants their expected frequency of customization and asked them to think about modular design as a basis for consideration. B1 envisioned that he may change the accessories (ring or earpiece) and modules (visual and haptic) a few times a day depending on the activity being performed. He also mentioned that if he was staying at home he would not change the design at all. B2 was not very interested in rebuilding the monitor often, but said that he might switch the modules for his chosen accessory, the wristband, for special events. B3 was enthusiastic about building monitors and mentioned that he would change accessories and modules every day so as to experiment with their uses. B2 and B4 wanted to customize the feedback mechanism but wanted an additional layer of digital control. Clearly, people were interested

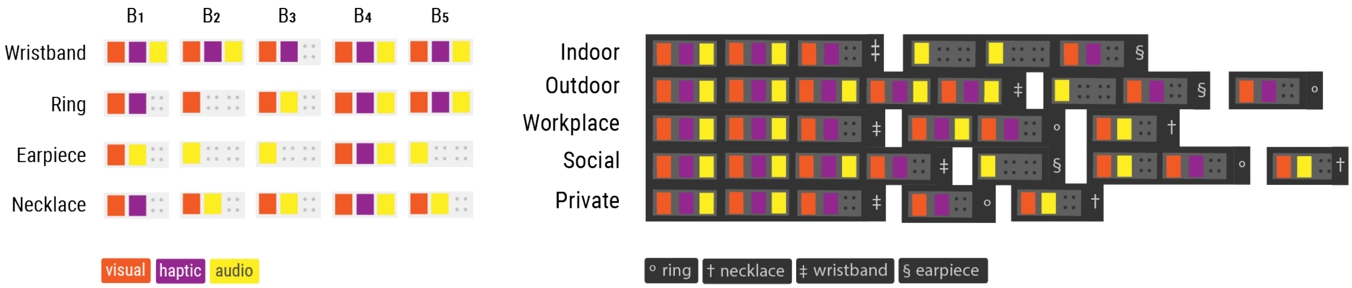

Figure 3: Tables showing the various configurations of feedback modules made by participants (*left*) per accessory type and (*right*) for different situational contexts.

in customization to different degrees and it seemed that, generally, participants who self-identified as makers (B3, B5) were more interested in customization.

6 DISCUSSION

Wearables for monitoring T1D are intended to be integrated into all aspects of one's daily life [19]. As noted from our interactions with the participants, end-users perception of wearability depends on personal preferences and the context of use. Throughout our research, it became clear that negative affective experiences could cause the misuse, or even non-use, of T1D technology. These affective experiences were often highly individual. Feelings such as frustration, annoyance, embarrassment, and discomfort were brought up again and again and often identified as influences that undermine best self-management practices. These experiences resulted in behaviour ranging from people leaving their monitors in their locker at the gym to concealing them on their person to the extent that they were almost inaccessible.

Adaptability proved to be important. Our participants' requirements changed with the context of use. A device with which they might feel perfectly comfortable at home might be considered inappropriate for wear in more socially complex environments. A device designed for evening dress might not be suitable for a business meeting. This opens up a design opportunity that can be addressed in several ways, with our work offering one such insight.

Aesthetic sensibilities also varied when it came to choices involving the use of wearable monitors. Like Pateman et al., we also think that aesthetics plays an important and currently underappreciated role in the use and continued engagement [23]. Although our simple prototype, assembled from off-the-shelf electronics, does not currently offer building sleek and small glucose monitors, we want to explore alternative possibilities in the future.

Our study also highlighted that everyone wanted to hide their devices, at least sometimes. In contrast, there are situations wherein monitors should not be discreet. For example, A3 said *"If you faint from hypoglycemia, you want those around you to be alerted to your condition, embarrassment be damned"*, and suggested that for such cases the device should look like a traditional glucose monitor. However, we find that "traditional" is a transitional quality and building on their previously expressed gratitude for general advances in technology, we think that perhaps with the introduction of aesthetically designed ubiquitous devices, people may be willing to more openly show their devices and in-turn create awareness, thereby changing our understanding of how health-related technologies should look.

As such glucose monitors can be designed either as single pieces of technology (as done currently) or modular pieces (as demonstrated in this research). While there are benefits to the former option, there could be additional scenarios wherein the individual modules could help. For example, modules could be shared or lent to someone else to monitor. B3 imagined a situation in which a newly diagnosed child playing hockey is wearing a sensor that relays to his mother in the stands who is wearing a second module, and this could be used to alert the mother of the condition while the child may be distracted by the game.

Lastly, the value of customization can be measured not only by the outcomes but also by the users' contribution to the design process [14]. As a result of the growing availability of 3D printers and online resources, we envision that end users can increasingly take on the role of designers if provided with appropriate design support tools for product design, programming and electronics circuitry and made specific to prototyping health technologies.

7 FUTURE WORK AND CONCLUSION

Going forward there are several avenues for improving our work. First, we would be interested in conducting more in-the-wild studies to gain further design insights informed by situational contexts and long term use of customizable glucose monitors. We also hope to improve our prototype and include software and hardware tools that help people author their own designs for modules. For example, TinkerCAD-like tools could be used to help people create CAD designs for glucose monitor modules to house their desired electronics. Ways to incorporate alternative materials (e.g., fabric, yarn, jewellery materials) for building the wearables are also interesting avenues for future work.

In summary, in this paper, we presented an exploration of design ideas and people's responses towards the use of customizable glucose monitor designs. We developed a simple prototype, *Diafit*, to facilitate participants' interaction with our concept. Participants developed various design options using *DiaFit* and expressed an interest in participating in the design and development of health monitoring devices. To state the obvious, not all diabetics are alike. Our research shows the importance of using inclusive design methods such as co-design to better accommodate the everyday, and often very personal contexts, which influence self-care. Our research focused on diabetes, but we believe the lessons learned offer broader implications, as wearable devices play an increasing role in healthcare.

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