Getting a grip on stress
Designing smart wearables as partners in stress management

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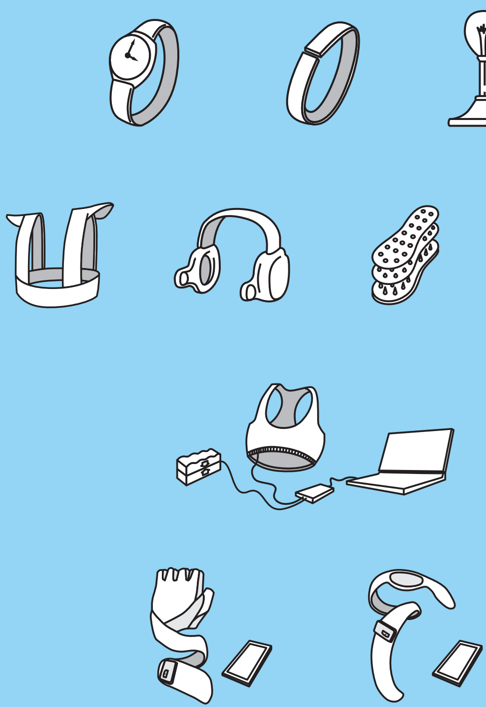

Xueliang Li

Getting a grip on stress:
Designing smart wearables as partners in stress management

Dissertation

for the purpose of obtaining the degree of doctor
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献给我的母亲，父亲，
哥哥，嫂子和侄子

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CHAPTER 1

Introduction

This thesis describes the exploration of designing smart wearables as partners in stress management. Given the increased capabilities of wearables to make sense of measured bodily and behavioural signals corresponding to stress and communicating this back to a person, an opportunity for developing such a concept is opening up. This thesis is driven by a vision that such a concept can provide inspiration and an initial direction for designers to conceive and shape such wearables. Thus, the work presented in this thesis should be read as an exploration to collect insights into how partnerships with smart wearables can be *conceptualised*, *expressed*, *realised* and *experienced*. Concerning our angle to stress management, we started with the ambition to help veterans with chronic posttraumatic stress disorder (PTSD). This group of people might benefit from smart wearables given that they may experience stress many times of the day. Providing a wearable that gives feedback on stress, helps to gain insights on what triggers their stress and actively helps them to calm down, could provide an additional source of support.

The following sections of this introductory chapter will discuss how this concept is informed by theories and applications of agent technologies, introduce chronic PTSD as the starting point for understanding its application and explain why this condition is an interesting case for smart wearables as partners. Based on this point of departure, we describe how the research journey unfolded, as the complexity of the phenomenon presented itself, which called forth more fundamental research questions that needed to be answered first.

1.1 Human-wearable partnerships

The motivation behind this work comes from the concept of human-computer partnerships as is studied in the research field of Human-Computer Interaction (HCI). Everyday physical objects, including wearable ones, are becoming 'smarter' by their embedded computation and electronic communication capabilities. The combination makes it possible to start thinking of these objects as 'intelligent agents' that make sense of the physical world, can reason about it, and act within it. This would radically change our perception of wearable objects, such as garments, clothing and accessories, that have, until recently, always been perceived as inanimate objects. The nature of our relationships with these wearable objects would change, as we can now form collaborative relationships with them. If wearable objects are perceived as intelligent agents they could start to fulfil roles in our lives, which were hitherto impossible. Such an exciting development appeals to adopting a conceptual and critical understanding of what this 'smartness' and 'partnership' might mean and how this could be made useful for people in real circumstances. To understand a partnership with smart wearables requires critically looking back at how the idea of computational partners has been discussed by other researchers.

The idea of perceiving computers as partners has a history in HCI. In 1997, Pohl argues that the *collaborative partnerships* between human users and computers are reflected in how computers can *assist* people to achieve complex tasks that are beyond human's capabilities while in other aspects of decision-making, such as conceptualisation and intuition, humans are "likely to be far superior" than computers (p.7). Compared to the *user-centred* design paradigm, Jacucci et al. (2015) proposed the notion of *symbiotic relationships* where both humans and computers maintain the goals and agency and collaborate based on shared resources and transparent communication. They, furthermore, suggest more balanced human-computer relationships in which computational artefacts should be considered as more than servants that follow orders of humans, but take the initiative to engage people in dialogues. The HCI notion of computational partners coincides with that of artificial intelligent agents.

Intelligent agents can be traced back to Dennett's (1987) "intentional stance" which suggests an approach to computational artefacts "as if" they had intentions and goals and could engage people in social interactions. Dennett's definition is one that is referred to as "strong agency". According to "a weak notion of agency" given by Wooldridge and Jennings (1995), computer systems that express one of these following properties can be considered to be agents: a) they can operate independently without direct interventions of humans or other things (*autonomy*); b) they can communicate with humans or nonhumans (*social ability*); c) they are reactive to environmental changes (*reactivity*); and d) they are proactive, i.e., they can take initiatives to engage the users in the interaction (*pro-activeness*). It is the combination of these properties that makes them different from objects. The definitions of weak- and strong agency inspire researchers and designers to investigate *agentic objects*.

Different expressive forms and usage of agentic objects are explored by researchers in HCI and Design. Examples include *social robots* that engage children in social interactions (Tielman et al., 2014) or help elderly in the self-management of chronic diseases (Looije et al., 2010). Cila et al. (2019) investigated intelligent agents as *products* by exploring three metaphorical references for designers to create meaningful and aesthetic products for the Internet of Things (IoT), i.e. the 'Collector', 'Actor' and 'Creator', which provides a direction to further inquire into the types of agency expressed by the products, the extent of the negotiation and delegation between the products and users, and ways in which their forms and behaviour should be shaped. That users have a different view of these objects than of more traditional objects is evident. For example, research on *conversational agents* shows that people who use self-tracking applications with conversational features tend to frame them as coaches and nurses (Erdeniz et al., 2020) or as companions (Rettberg, 2018). Marenko (2014) who discusses how smart objects can be understood through modern interpretations of animism, inspired

Rozendaal et al. (2019) to take up this idea as a design approach. They propose the notion of 'Objects with Intent' (OwI's) with the aim to provide direction to the design of everyday things as collaborative partners. Seen from this perspective, smart wearables can be seen as a subclass of those objects as they are designed to display intent and have agency.

Smart wearables designed as everyday collaborative partners enable new ways of using agents. First, smart wearables are characterised by their *continuous presence* in humans' everyday activities. Wearable sensors make it possible to generate personal data by sensing bodily changes, physical and online activities (Chan et al., 2012). Examples include wearable applications for fall detection (e.g. Pierleoni et al., 2015) and emergency alarms for elderly (e.g. Miller et al., 2015). Second, smart wearables represent one's *self-perceived identity*. For example, people wear smartwatches not only as a piece of technology but also as a fashion accessory which are visible to others and show their lifestyles (Chuah et al., 2016). Third, wearable technologies involve the *human body as part of the user interface*. As mentioned by Motti (2020) interaction design of wearable devices requires considerations on multisensory experiences and the body language of the person. This leads to wearable devices that connect to the human body as sensorial and behavioural wholes, instead of being distinct and alien to it. Their characteristics of being continuously present, representing one's own identity, and involving the human body as part of the dialogue make smart wearables a unique way of using agents. And such 'wearable' agents that can help people to deal with stress in ways that other products can not. Below will explain why dealing with stress, especially PTSD as a chronic condition, is an interesting case to start exploring the design of smart wearables as partners.

1.2 Stress management

The ambition of this PhD project starts with veterans with chronic PTSD as our target group because they experience stress continuously and need timely support in varying everyday contexts. PTSD is a type of stress disorder that develops in people who experience traumatic events such as natural disasters, wars, and car accidents (Friedman, 2015; Vermetten et al., 2018). A typical group of people who have PTSD are post-deployment veterans. A 2013 survey of 60,000 Iraq and Afghanistan veterans shows that 13.5% of the participants are screened as positive for PTSD (Eber et al., 2013). Typical PTSD symptoms include negative thoughts, intrusive memories, and fierce physical arousal and behavioural reactions that can be triggered by the situations which remind them of their traumatic experiences (Friedman, 2015, p. 6). Such PTSD symptoms can last for a long term, and sometimes even lifetime. In addition, people with PTSD can experience a psychological state when exposed to reminders of trauma (referred to as ‘flashbacks’), in which they might lose connection with the present and behave as if the trauma occurs (Friedman, 2015, p. 16). When experiencing such moments, people with PTSD are not aware of their own physical states as well as the present surroundings. These *chronic*, *intrusive* and potentially *overwhelming* aspects of PTSD make veterans with PTSD a socially relevant case for whom smart wearables as partners could be a valuable aid.

Smart wearable technologies can be used complementary in therapeutic interventions for people with PTSD. Treatment for PTSD includes variants of cognitive behavioural therapy (CBT) which aim to guide people to develop and reinforce positive ways of processing traumatic memories and thus take control over their thoughts, feelings and behaviours (Friedman, 2015, p. 38). Technological applications for veterans with PTSD have been developed within and outside clinical settings. Some of the technologies are used to provide technology-facilitated variants of cognitive behavioural therapies (CBT). For example, virtual reality (VR) has been used to provide interactive and immersive representation of traumatic memories in exposure therapy for PTSD. Rizzo et al. (2014) created *Bravemind*, a virtual reality system for delivering prolonged exposure therapy (VRET) for patients with combat-related PTSD symptoms. Another example is 3MR_2 which is a home-therapy system where a virtual agent could guide the PTSD patients to recollect and reconstruct their traumatic memories in a self-built 3D world (Tielman et al., 2017). However, these treatment and technological interventions focus on guiding people with PTSD through therapeutic processes in fixed settings and over a limited timespan. People with PTSD, especially those who experience it as a chronic condition, face the challenge of living through many daily situations as being stressful. Not many wearable applications, other than wrist-worn devices, such as smartwatch applications (e.g. Latour et al., 2020) and smartphone applications (e.g. Possemato et al., 2016; Rodriguez-Paras & Sasangohar, 2017), can be found that could help people with PTSD in daily stressful situations. It seems that smart wearables designed as partners is a new concept that warrants exploration of the possible interactions with it, the technologies to realise the design and the experience interacting with it.

1.3 Research questions

Now that the ambition and motivations have been introduced, we formulated the research questions that guide our research required to arrive at an understanding of designing smart wearables as partners for veterans with chronic PTSD. However, the exploration undertaken in this PhD project revealed the complexities of this design challenge—on technical, social, and ethical levels—which required deviating from this initial goal by addressing more fundamental research questions that needed to be answered first. Each question stated below contributes to our research objective to explore and gain insights into how partnerships with smart wearables can be *conceptualised*, *expressed*, *realised* and *experienced*.

- **RQ1:** (Conceptualisation) *what could partnerships with smart wearables be like for veterans dealing with chronic PTSD?*
- **RQ2:** (Expressiveness) *how can partnerships be expressed through smart wearables?*
- **RQ3:** (Realisation) *how can smart wearables as partners be realised?*
- **RQ4:** (Experience) *how do people experience wearing and interacting with a smart wearable during the day?*

RQ1 started the process of inquiry and aligned with the initial ambition to help veterans with chronic PTSD deal with stress. The following three research questions (RQ2-4) emerged during the process as necessary intermediate steps towards realising our initial ambition. The next section introduces our research approach and the embedding of the four research questions in our studies; see Figure 1.1. for an overview.

1.4 Approach and setup

This PhD research followed a Research-through-Design (RtD) process. This approach could be traced back to the phrase “Research through Art and Design” coined by Frayling (1993) who recognized the knowledge achieved and communicated “through art, craft or design” and gave examples from the practice of materials research, product development and action research. Stappers and Giaccardi (2017, p. 12), defined RtD as the way of doing research in which design activities “play a formative role in the generation of knowledge” or, as they simply state, “doing design as part of doing research.” RtD is not a methodology that gives strict step-by-step prescriptions. Instead, RtD exists in many forms, sometimes goes by different names, is conducted in different settings ranging from ‘lab’, ‘field’ or ‘showroom’ (Koskinen et al., 2011) and is being practised by individual researchers across different research contexts (Boon et al., 2020). Wensveen and Matthews (2014) described RtD as the research which has “designed things as components of the research process” with the focus on the particular roles played by the prototypes, such as “a testable physical hypothesis”, “a means of inquiring into a context of use” and “a research archetype”. What makes this PhD project a particular case of RtD is its unfolding and—in retrospect—the *reflexivity* required to identify and report on changes that occurred during the design and research process. It is articulated below how the research unfolded as an exploration led to insights into how partnerships with smart wearables can be *conceptualised*, *expressed*, *realised* and *experienced*.

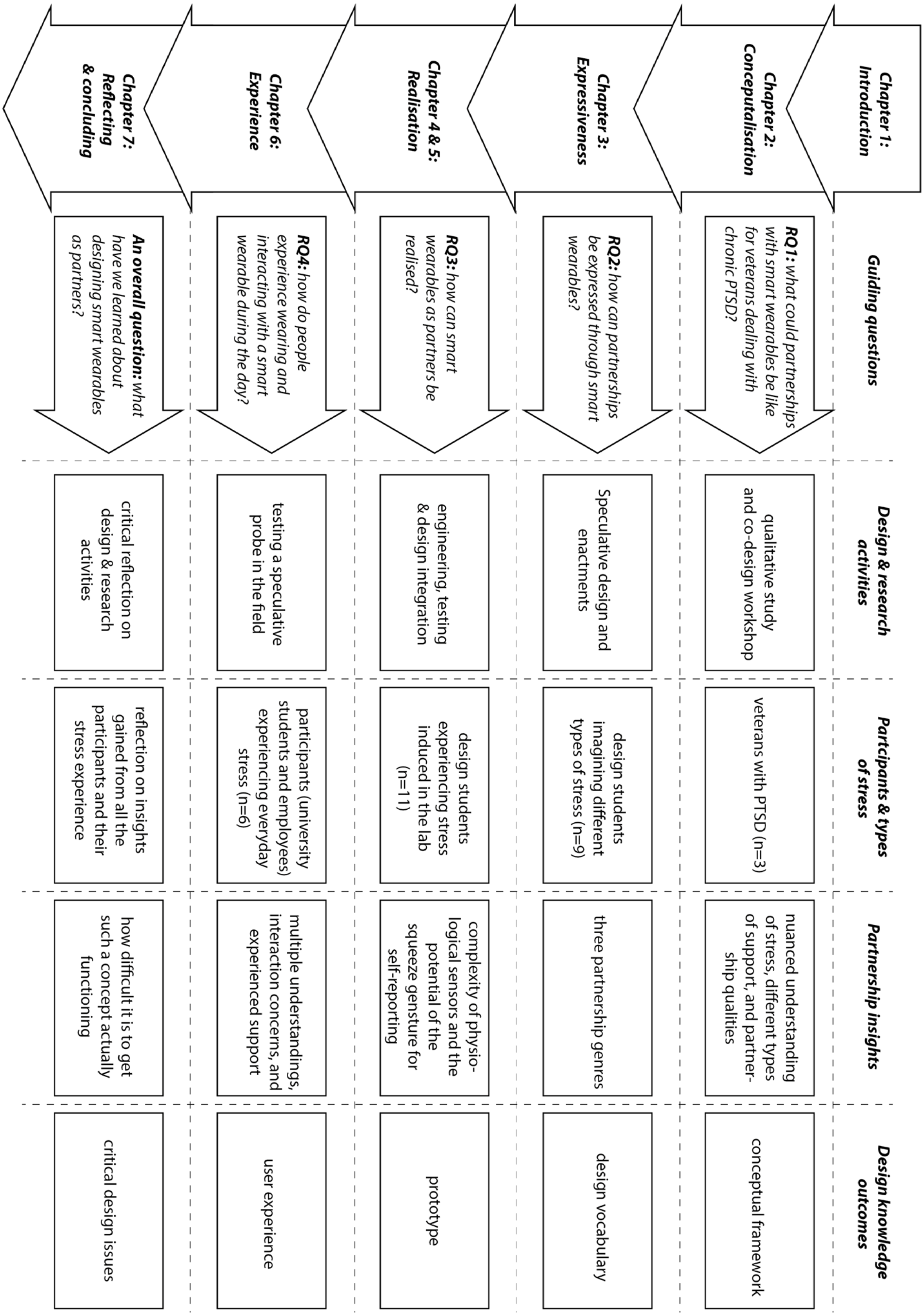


Figure 1.1. Thesis outline. The chapters answer the research questions following the RtD approach: design activities (making of prototypes and using the prototypes as speculative probes) are integral parts of the research process of generating different formats of the design knowledge.

Conceptualisation

The work conducted and presented in Chapter 2 initiated the research with the question of *what partnerships with smart wearables could be like for veterans dealing with chronic PTSD (RQ1)*. This research was set up to better understand the problems veterans with chronic PTSD face and how they imagined smart wearables to provide support. A qualitative study was conducted to get an impression of how veterans with chronic PTSD experience and cope with stress in daily life. Following this, a co-design workshop was organised with veterans to learn how they themselves envision smart wearables in the future. By reflecting on the work, a conceptual framework is proposed that highlights the key aspects to consider when designing smart wearables as partners, including aggregation of multiple sources of data to understand the person and the situation, providing appropriate types of support, and the experiential qualities (i.e. *trustworthiness*, *respectfulness* and *discreetness*) that are considered relevant when relating to a smart wearable as a partner.

Expressiveness

The work conducted in Chapter 3 is driven by the question of *how partnerships can be expressed through smart wearables (RQ2)*. Since partnerships with smart wearables indicate mutual and collaborative relationships, how are these relationships expressed through smart wearables and by the interactions they afford? Design students were asked to participate in a speculative design and enactment workshop, in which they imagined smart wearables that help people manage their stress in different stressful situations. This provided the 'backdrop' for their design explorations, giving meaning to it, yet did not capture the chronic stress condition that veterans are dealing with. Our reflection on the speculative designs crafted and enacted by design students led to the understanding of partnerships as *organs*, *collaborators* and *mentors*—to be considered as three genres of human-wearable partnerships—expressed through a wearable's physical and temporal form, and ways of affording particular kinds of interaction. We reflect on how these genres can be understood as *designerly vocabularies* to support the crafting of digital and physical materials to help shape wearable partners.

Realisation

To be useful as partners we need to investigate to what extent smart wearables can actually sense stress and how they can engage in dialogue with people wearing them? In Chapter 4 and 5, the realisation of smart wearables was explored and informed by the third research question: *how can smart wearables as partners be realised? (RQ3)*. Different sensors were applied and integrated in a garment and a tangible self-reporting interface (a squeezing bar) and tested on their performance with design students in the lab by using a psychological stress inducement experiment. We learned how difficult it is to technically obtain good data from these sensors and arrive at a conclusion about the level of stress a person experiences. However, we saw the value for using the gesture of 'squeezing' as a means for self-reporting stress. In Chapter 5, we then describe the process of making a smart glove, named *Grippy*, as an interactive prototype to encourage people to seek out potential stressful situations and learn to cope with stress by means of stress exposure training. The design is informed by the conceptual framework, the three partnership genres, and utilised the 'squeezing' interaction technique.

Experience

To design smart wearables as partners for veterans with chronic PTSD as an ultimate goal, we need to know more about how smart wearables are experienced when worn and used on a daily basis. In Chapter 6, we therefore have deployed Grippy as a speculative probe in the field to learn more about *how people experience wearing and interacting with a smart wearable during the day (RQ4)*. University students and employees without stress disorders (known to us) were asked to wear and use the prototype for five days successively. We learned how Grippy triggered interaction concerns and multiple understandings, which shed light onto the ways in which partnerships with smart wearables may form and the kinds of support they may provide. We also analysed to which extent Grippy has been experienced to be an organ, a collaborator and/or a mentor. This analysis made us critically reflect on the issues that hindered the perception and use of smart wearables as partners. Starting with non-PTSD participants in this study was a modest, but essential intermediary step towards our ultimate long-term goal of understanding how veterans with chronic PTSD might experience and feel supported by a smart wearable like Grippy. The chapter concludes with a discussion on how smart wearables may be used in mental health interventions.

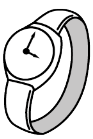
Reflecting

Chapter 7 deals with *reflecting* and *concluding* on the work. We reflect on how the RtD process unfolded itself concerning the alignment of research and design activities, how prototypes have been used as research tools and how the PhD researcher needed to combine different roles during this process. We discuss how—in retrospect—'reflexivity' is important to help identify changes that occur and how to adjust to them along the way. Then, the learnings presented across the different chapters are critically reviewed concerning the extent they have deepened the understanding of designing human-wearable partnerships and how—because of the complexities encountered during the project—they were not yet able to deliver on the initial ambition to help veterans with chronic PTSD manage their stress. This chapter also discusses some of the ethical concerns that presented themselves during this project. Chapter 7 ends with a general conclusion of the thesis.

Chapters of this thesis have been partially published. Chapter 2 and 4 are adapted from published manuscripts in a journal (Li et al., 2021) and a conference (Li et al., 2020), Chapter 3 and Chapter 6 are adapted from manuscripts submitted to journals which were under review at the time that the thesis was synthesised.

CHAPTER 2

Things that Help Out: Designing Smart Wearables as Partners in Stress Management



This chapter is based on:

Li, X. (Sean), Rozendaal, M. C., Jansen, K., Jonker, C., & Vermetten, E. (2021). Things that help out: designing smart wearables as partners in stress management. *AI & SOCIETY*, *36*(1), 251–261. https://doi.org/10.1007/s00146-020-01003-0

The changes made were to align the chapter with the reflections presented in Chapter 7.

In this chapter we propose a conceptual framework for designing smart wearables as partners to help veterans with chronic PTSD cope with stress in daily contexts. This framework considers how smart wearables can be designed as partners that consider both the person and the situation so as to provide appropriate support. We describe how this design vision is inspired by the technological capabilities of smart wearables, therapeutic partnerships with humans and animals, and human-computer partnerships in HCI. To develop a framework to achieve this vision, a qualitative study and a co-design workshop with veterans with chronic PTSD have been conducted. From the results we identified design opportunities and challenges to design wearables as partners that would help them deal with stress.

2.1 Introduction

> *On my wrist, I have a bracelet. It senses my pulse, respiration, and has a GPS system. It knows how to help me deal with my anger, and it has witnessed many difficult moments I've been through. It's my best friend. One day, we were at a 'Guns 'n Roses' concert. Before we set out for the concert, I tenderly rubbed the surface of the bracelet to tell it I was in a good mood, so that it would be lenient with me. While we were waiting outside the entrance, more and more people joined the line. The bracelet sensed my agitation and started to contract gently. Feeling this made me aware of my rising tension. I looked for a distraction by talking to my wife and my friends. After we were seated, it was my turn to get beer. Seeing the crowded line at the bar made me nervous and the bracelet started to contract again with a bit more intensity. As I joined the line, I tapped the bracelet with my fingers to let it know I was OK. When it was my turn to order beer, somebody suddenly jumped in front of me. I started shaking with anger! The bracelet grabbed me firmly by my wrist and I realised I needed to step out of the situation before I would lose my temper. I went back to my friends to ask if they could order beer for me…*

Above is a fictional scenario given by Jason, aged 57, a war-veteran who was diagnosed with post-traumatic stress disorder (PTSD) after his military service. Dealing with stress is a chronic condition that he has to face on a daily basis. In a co-design workshop, Jason proposed this concept of a bracelet to help him deal with stress. As can be seen above, the bracelet *senses* Jason's stress not only via his bio-signals (pulse and respiration) and contextual information (location), but also through direct *dialogue* with him (rubbing and tapping). Based on this, the bracelet provides personalised advice by contracting at different levels of intensity which helps him take action. Jason further described this bracelet as his "best friend" who knew him well and on which he could always rely.

This example illustrates how smart wearables could help people manage their daily stress *as partners*. In this chapter we propose a conceptual framework that introduces the notion of partnership, adding to current developments in the use of smart wearables for daily stress management. Stress is an important aspect of mental health which, if not dealt with properly, could result in reduced quality of life, inefficient work, and even chronic diseases (Anderson et al., 2012; Steptoe et al., 1996). Given the increasing capabilities of wearable technologies to measure bodily and behavioural changes of a person and feedback this information to the individual, the opportunity of designing smart wearables as *partners* to help people in stress management, has opened up. We therefore propose a conceptual framework that provides a direction to associate the multimodal sensing of stress and the type of support with the intended partnerships the user may form with the wearable.

In the following sections, we present the motivation and inspiration of this framework by examining technological capabilities of smart wearables, therapeutic partnerships in stress treatment and practice, and theories of designing computers as *partners* in human-computer interaction (HCI). Based on this, we conducted a qualitative study and a codesign workshop in which three veterans with PTSD and their spouses participated. Results of this study provide an empirical basis on which we interpret design opportunities and challenges in order to design smart wearables as partners. We discuss how this study helped us to substantiate the conceptual framework and conclude this chapter by reflecting on limitations of this study and directions for future work.

2.2 Developing a conceptual framework

2.2.1 An integrated perspective on stress

Stress is a complex phenomenon that requires combining both physiological and psychological perspectives to thoroughly understand it. Multiple physiological changes occur when people experience stress (such as changes in heart rate, blood pressure, and respiration), which coincides with the process of the body to prepare for a "fight-or-flight" response (Lovallo, 2015). Stress is also a psychological concept. Lazarus and Folkman's (1984) classic transactional model of stress forms the basis for such an understanding. In this model, stress emerges as a result of the exceeding demands of the environment on a person's perceived resources. Whether stress can be reduced or it may accelerate to prolonged stress depends on the individual's ability to deal with the sources of stress (problem-focused coping) or to regulate its emotional effects (emotion-focused coping). Minor stressors that emerge from everyday activities (known as "daily hassles") might, if not dealt with properly, lead to the development of stress disorders or the aggravation of existing stress symptoms (Brantley & Jones, 1993; Nicolson, 1992).

2.2.2 Wearable technologies for daily stress

Current wearable technologies are capable of sensing stress from multiple sources. Physiological sensors can provide proximal information about people's current stress state. Research also shows the possibility to indicate a person's level of stress through analysis of people's (online) activities, such as the use of phone applications (Ferdous et al., 2015; Wang et al., 2014), working schedules (Bakker et al., 2012), tasks a person is working on (Mark et al., 2014), and posts on social media (Reece & Danforth, 2017; Schwartz et al., 2014). These methods provide useful information to help identify potential causes of stress and predict upcoming stressful events. However, these are privacy sensitive and should be applied with care. Other methods of sensing include smartphone applications through which users can report on their stress by means of tags or texts (Adams et al., 2014). These methods require a person's conscious attention and therefore can be experienced as being disruptive in daily activities (Schmidt et al., 2018; Kusserow et al., 2012).

A variety of commercial products and research prototypes are available that help reduce stress. Examples include those that send 'just-in-time' stress notifications to users based on sensed bio-signals (Cruz et al., 2015). The challenge is to decide the threshold at which point to send such signals (Garcia-Ceja et al., 2018). Furthermore, research conducted by MacLean et al. (2013) shows that synchronous representation of stress might even worsen the situation. Other applications have been designed that translate biofeedback into visualisations to trigger retrospective self-reflection (e.g., Sanches et al., 2010). However, this may result in people feeling overwhelmed or ashamed by such data (Kelley et al., 2017). Several commercially available products such as Apple Watch and Fitbit combine bio-sensed signals of stress with relaxation exercises. We also found applications that target people with mental illnesses by applying therapeutic methods. For example, smartphone applications that provide platforms for communication between people and mental health professionals and those providing peer support by initiating conversations amongst people who have the same mental issues (Donker et al., 2013; Smedberg & Sandmark, 2012). We also found research projects that explored smart wearables in emotional communication through the use of tangible interfaces. For example, Uğur et al. (2011) developed a set of form-changing garments as ways of communicating emotions between couples.

Despite the variety of sensing and intervention methods provided by wearable technologies, many wearables for stress management are designed as detection and representation tools that follow a "diagnose-and-warn" approach (Sanches et al., 2010). Few wearables are designed as intelligent agents that could form *partnerships* with wearers. Smart wearables, by being continuously present, engaging wearers in dialogues, and providing support when needed, show the potential to help people manage stress as partners in ways other products can not. However, it seems a new concept that warrants conceptual exploration. As the first step in this exploration, we searched for inspiration from human and animal *partners* that help people manage stress.

2.2.3 Partnerships as therapeutic relationships

We draw inspiration from three types of partnerships identified in stress treatment and self-management: *client-therapist*, *interpersonal,* and *human-pet partnerships*. First, therapists serve as professional partners in stress management. The partnership between therapist and patient is built on expertise and empathy. Therapists maintain an objective perspective when analysing patients' stress and its causes while also being empathic to their personal experiences and circumstances. They are trained to be sensitive to problematic issues and to be able to recognize "warning signs" of stress (Miller, 1998). They provide people with practical techniques and skills to cope with stress, and help them develop positive ways to perceive what triggers their stress (Friedman, 2015).

Second, *interpersonal* partners are the people in a person's social network who are able to provide help. When faced with stress, people tend to seek help from others, such as family members, spouses, coworkers and friends. Such partners help by providing information and advice, assistance, comfort, care and love (Patterson, 2003). Interpersonal support provides a "buffering effect", protecting the person from negative effects of stress (Cohen & Wills, 1985).

A third and interesting partnership is that between humans and animals, such as *pets*. Holbrook et al. (2001) claims that the human-pet companionship resembles that of humans' in providing care and comfort, self-reflection, and in-depth communication (if not verbal). Another study shows how dogs could motivate their owners to stay physically active (by needing to be walked, played with, and cared for) and thus help them lead a healthier lifestyle (Dotson & Hyatt, 2008). Partnerships with dogs can also be observed in service dogs that help people cope with chronic stress by being sensitive to their emotions and provide support through companionship (Vincent et al., 2017; Yount et al., 2013).

2.2.4 Computers as partners

Considering computers as partners is not new in the field of HCI. With the increasing number of 'intelligent' computational products being introduced in society, more attention is being paid to the interdependencies and collaborations that may exist between humans and computational products. In 2015, Jacucci et al.

proposed the concept of partnerships as 'symbiotic relationships' where both humans and computers maintain independent goals and agency. Farooq and Grudin (2016) talk about the collaboration between humans and computers in terms of 'negotiations' that are required to achieve an understanding of shared objectives and how to attain it together. In design, Rozendaal (2016) emphasises how smart everyday things can be designed as collaborative partners that empower people to engage in activities which they are otherwise unmotivated for, or unable to carry out. Cila et al. (2017) suggests using agents as a metaphor to describe the affordances, challenges, and opportunities engendered by current and future smart networked products. Their work provides inspiration on how computational partners could be designed to appear and behave like everyday objects.

2.2.5 Designing smart wearables as partners

Based on the discussion above, we propose a conceptual framework for designing smart wearables as partners. We suggest designing the interaction between the wearable and wearer as an ongoing dialogue through which the wearable can build up an understanding of the person and situation, and provide appropriate support. This framework is composed of three aspects that designers should take into consideration, as shown in Figure 2.1. By means of sensing, we suggest designers be aware of how combining different kinds of data (physiological, behavioural, contextual, and subjective data) can provide an understanding of a users' stress situation. With providing support, we refer to how the interaction with smart wearables might change a user's behaviour and help reduce stress. Finally, we suggest designers pay attention to the qualities that help users develop partnerships with smart wearables. What we would like to find out is how the framework can be substantiated by the target group's (i.e., veterans with chronic PTSD) real-life stress experiences and anticipation about the future use of smart wearables. For this purpose, we conducted an empirical study.

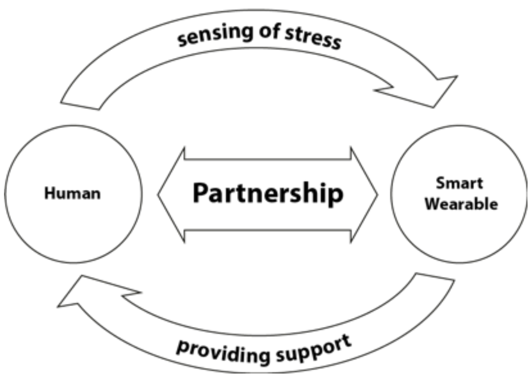


Figure 2.1. A preliminary framework of designing smart wearables as partners.

2.3 Empirical study

2.3.1 Aim of this study

To answer the question of *what partnerships with smart wearables could be like for veterans dealing with chronic PTSD (RQ1),* we set out to discover opportunities and identify challenges when designing smart wearable as partners for this particular group of people. Specifically, we focused on three aspects regarding the questions of (1) what could be sensed by smart wearables to achieve an integrated understanding of the stress an individual experiences and the situation he/she is in? (2) how could smart wearables support the individual to deal with stress? and (3) what experiential qualities of smart wearables are needed to be perceived as partners? PTSD is a stress disorder developed after experiencing a traumatic event (Friedman, 2015; Vermetten et al., 2018). A typical symptom of PTSD is that people feel tense on a daily basis and can be easily triggered by stimuli that remind them of their traumatic experiences. Post-war veterans are a group of people who are especially vulnerable and have a high chance of developing PTSD after their service (Yehuda et al., 2014). We chose veterans with chronic PTSD as a target group because they experience stress on a daily basis and therefore are a potential target group who could benefit from the concept of smart wearables as partners that we propose.

2.3.2 Participants

Three veterans with chronic PTSD participated in the study. They were recruited through veteran organisations and a mental healthcare institution. Their spouses were also involved as they could support the veterans when needed and provide complementary information related to the veterans' stress experiences. Below is a brief overview of the participants and their spouses. Their names have been replaced with fictional ones for anonymity.

Jason, aged 57, was recruited by the military at 16 and sent on a military mission at age 20. After his service, he worked for several years until he was diagnosed with PTSD and became unemployed. He received treatment between 2004 and 2010, and has now returned to work at a security company. His wife, Mara, is a psychiatric nurse. They have three daughters and another two daughters from Jason's previous marriage.

Pete, aged 47, has been undergoing therapy for years, including 9 months' initial treatment, and two years of cognitive behavioural therapy (CBT). He is the chairman of a veteran association and occasionally volunteers at a local community sport club. His wife, Mary, aged 46, works for an internet company. They have three sons, one of them from Pete's prior relationship.

Jack, aged 58, was diagnosed with PTSD after his return from military service. He has undergone a variety of treatments since then, including CBT, and experienced difficulties in getting back to work. Years ago, he experienced a severe scooter accident that caused him to experience constant physical pain, which also worsened his mental condition. He is married to his second wife, Catherine.

2.3.3 Procedure

After confirmation, each couple was invited to an introductory meeting where they were introduced to the content of the study and signed their informed consent. They were given contact information of a psychiatrist in case psychological support was needed. Our study consisted of three parts: (1) Vlogs, (2) follow-up interviews and (3) a co-design workshop. In the first two parts, we learned about the participants' daily stress experiences. In the third part, a setting was provided where they were facilitated to design smart wearables as partners with the assistance of a design student. A native Dutch-speaking research assistant conducted the interviews, helped with the co-design workshop, and acted as the main contact person.

Vlogs

The veterans were asked to share self-made videos (5 - 15-minute vlogs) with the research assistant through WhatsApp^{tm} throughout the course of one week. Their spouses were encouraged to assist in making these vlogs. Specific themes were assigned to them each day. On the first two days, they were asked to introduce themselves and show *a day in the life*. On the third day, they were asked to talk about *the things they carried with them on a daily basis* to inform us about the objects they often use, and how they wear or carry them. On the fourth and fifth day they shared stressful moments they encountered in daily life and talked about how they would like to handle them in the future. On Day Six, the topic was about support from *the people you care about*. And on the last day, they reflected on their experiences over the past week.

This method is adapted from the self-reporting diaries in user-centred design research (Sanders, 2002). We chose this method because it allows the participants to express themselves freely without the pressure caused by researchers being present. The content of the Vlogs uploaded by the participants were reviewed by the researcher to identify interesting topics, which would be revisited in the follow-up interviews to learn more about them.

Follow-up interviews

All of the interviews were held at the participants' homes, and lasted from 30 minutes to two hours. The interviews followed the same structure as that of the vlogs (see Appendix 1 for the interview script). Preliminary findings from the vlogs were used as triggers of the conversation. All interviews were audio-recorded.

Co-creation workshop

Two veterans, Jason and Pete, and Mary (Pete's wife), were able to join a co-creation workshop. The aim of the workshop was to enable the participants to design smart wearables for their own use. Three design students joined them and they formed three teams of two. In the workshop, each team was asked to produce an *experience map*. We adapted this tool from a user-research toolkit (Path, 2013) to provide a structured template to capture the veterans and the spouse' feelings, thoughts and actions throughout different phases of particular stressful situations. Based on these situations, each team proposed a design concept. Mock-ups of these concepts were made by using tinkering materials such as scissors, tape, Velcro and fabrics, which were then used in storytelling to explain how their designs could help them overcome stressful situations.

2.3.4 Data management and analysis

Data was collected from three sources: Vlogs, the follow-up interviews, and presentations of participants' work (experience maps and mock-ups) in the workshop[1]. The Vlogs and audio recording of the interviews were transcribed and translated from Dutch into English. The data analysis was informed by phenomenological research methods (Moustakas, 1994) and qualitative content analysis (Hsieh & Shannon, 2005). Three steps were taken to interpret the qualitative data following the bottom-up and top-down approach. First, the PhD researcher (author of this thesis) went through all the data multiple times. Specific words or sentences were highlighted that referred to unique aspects of experience with preliminary interpretations noted besides these quotations (bottom-up coding). Second, the PhD researcher organised the specific insights informed by the three aspects of the framework (top-down coding), i.e., *means of sensing stress*, *ways of providing support* and *experienced partnership qualities*. Finally, three other researchers (the PhD supervisory team members) were invited to a discussion to review the insights and to arrive at consensus. Results of the study, as presented below, include not only direct quotes of the participants (which are referred to in quotation marks), but also design opportunities which originate from the responsible researcher's *interpretation* of the qualitative data gained from the study.

2.4 Results

Results of the study are grouped according to the three aspects of the conceptual framework: means of sensing, ways of providing support, and ways in which

[1]The anonymized transcription of the interviews and the workshop can be accessed through an online repository system (https://surfdrive.surf.nl/files/index.php/s/kEzXGanZE4uvhUe).

smart wearables could be experienced as partners.

2.4.1 Means of sensing stress

Understanding the person

All three veterans talked about situations in which they were stressed and agitated but were unaware of the stress at those moments. Catherine, Jack's wife, recalled what she saw when she and Jack were waiting in line at an airport: "He started sweating and I could see he was getting restless." She added that Jack seemed unaware of it. Pete responded to this point by saying that he was always too late becoming aware of his increasing stress. Pete commented on his issue of anger using the metaphor of a rage-thermometer: "For anyone it may be 30 or 40% but I go up to 100% in no time." Jason, Pete and Jack mentioned how they struggled with their behaviour caused by agitation. For instance, Jason said he sometimes showed fierce reactions when someone suddenly touched him and Pete mentioned that he would use bad language and could raise his voice whenever he felt threatened. Jack even got into a fight when someone bumped into him by accident.

The veterans maintained objective perspectives when reflecting on their stress issues. Pete regretted his behaviour when he confronted a lady who cut in line at a bus stop; he admitted that the problem is that he always became aware of this too late. Jason recalled how he overcame his fear of going outside his house step by step. He said he would train himself to be exposed in the situation even though he knew that would wear him out. He also pointed out the significance of "training your physical strength, and not avoiding problems" so that he could return to society. He also shared his comments on the stigma of being a patient and a damaged veteran. He related to people who are like him: "That is basically the worst part… it makes people lose their dignity."

Results of the interviews show that veterans are sometimes not aware of the rising tension leading to angry outbursts. For us, this indicates the value for smart wearables that monitor stress continuously and provide support when needed, especially before stress escalates to the degree that people lose self-control. Their story further inspires us to think about how smart wearables can be used to help people become more sensitive about their stress through training exercises.

Understanding the situation

We recognized specific environmental stimuli that caused the veterans' stress. All three were especially triggered by unfamiliar places and people. Jack mentioned that visiting the supermarket really drove him mad and Jason talked about his high alertness whenever he went outside. Other triggers include unexpected objects or sounds. For example, Pete shared his fear of thunderstorms and fireworks which gave him "a terrible fright." Jason expressed his high tension raised by unexpected encounters with people "if suddenly someone touches me [him] when I [he] don't see it coming."

We also discovered that veterans' stress could be triggered in social situations where they were confronted with the behaviour of others that contrasted with their personal values, or when they felt undermined or disrespected. For example, Jack mentioned his immediately increasing tension when he saw a young man cutting the line in a snack shop. Pete commented that he was especially annoyed by his teenage son lying on the couch with eyes on the phone while talking with him, which he referred to as a sign of disrespect.

These insights led us to consider how analysing individual stress data in relation to environmental data might help identify what contextual triggers of stress are. For instance, smart wearables could mark particular physical locations (via GPS trackers) found to correlate with increased stress levels. This data can then also be used in applications that help people prepare for potentially stressful episodes. However, it may be difficult to detect sources of stress beyond geographical locations. Examples are interpersonal conflicts in which stress might be experienced differently by different people involved. This combination of individual and contextual information can provide an understanding of how stress might be triggered in particular settings and opens up a range of possibilities to help people cope with stress.

2.4.2 Ways of providing support

Raise awareness

We realised the importance of participants to become aware of stress in a preferred and timely manner. Pete expressed his desire that someone could remind or even stop him when he was about to lose control. In the co-design workshop, he designed a smart watch which could send a 'beep' sound and vibration. He commented that these strong and firm signals could pull him back to reality and make him more aware of his behaviour in relation to others. In contrast, Jason preferred quiet and private signals as feedback, as demonstrated by the bracelet described in the introduction. Mary designed a smart table lamp which could sense and moderate tensions that may arise during family conversations. With this design, she hoped that family members would be more aware of the influence of their behaviour on others. Although a table lamp does not count as a wearable, we included this design as it expresses the need for managing stress in family situations. The table lamp could sense tension in group conversations by detecting the "tone of voice" as a collective measurement that changes the colour of the light emitting from the lamp, from white to red, as the tension rises. Because of this collective measurement, Mary explained how nobody could feel pointed at, or be judged for triggering the signal.

Assisting coping behaviour

Based on the designs created by the veterans in the workshop, we identified a number of coping behaviours that can be assisted by smart wearables. In the design of Jason, the different intensities of the bracelet made him realise the level of urgency of the situation, and whether he should withdraw and ask for help from others. Similarly, the smart watch designed by Pete sent a warning signal (sound and vibration), which was interpreted by him as an indication that he should withdraw from the situation before he would lose his temper. When interpreting their stories, we note that the extent these signals invites users (veterans) to take action, largely depends on personal interpretations and preferences. This raises the consideration of self-tailored signals of smart wearables, and the training process through which people could associate the signals with particular behaviours that smart wearables intend to elicit.

Mobilising human support

Veterans mentioned the support they received from their social network when dealing with stress. All three veterans expressed their gratitude towards their spouses for supporting them through difficult times. Mary, Pete's wife, described her role as a mediator in solving conflicts between Pete and their children, by talking to each other after a fight. Jason expressed his thanks to his wife, Mara, for her understanding and emotional support. How can this emotional support provided by spouses be promoted by the use of smart wearables? Little evidence was found in stories of the participants though, this could be an interesting design direction to further investigate. In addition, Jason mentioned the possibility of sharing his stress-related data (collected by the bracelet) with the therapists, saying that: "This (the bracelet) can be given and used by therapists before an appointment. Therapists can log into your account and see how many stress moments you have had and see what happened."

To summarise, we see how smart wearables could help people deal with their stress by raising awareness, assisting existing coping behaviours, and mobilising social and therapeutic support. Examples given by the participants lead to the interpretation that people can perceive the signals of wearables differently and associate them with particular coping behaviours. With regards to this point, we see the possibility of integrating artificial intelligence in the design of smart wearables, which can play an important role in tailoring these specific forms of support. Although some AI techniques such as machine learning algorithms have been used to train wearable systems to be more accurate in recognizing stress (Garcia-Ceja et al., 2015; Grünerbl et al., 2014), a review of the field of digital health interventions shows that more work should be done with respect to interventions and their effects in real life (Triantafyllidis & Tsanas, 2019). Furthermore, interpretation of the quotes of the participants inspired us to envision future design of smart wearables that could facilitate human support provided by their spouses and mental healthcare professionals.

2.4.3 Partnership qualities

In this section, we introduce three partnership qualities that we identified in the explanations that the participants in the design workshops gave on the designs they created, i.e., *trustworthiness*, *respectfulness* and *discreetness*.

Trustworthiness

One of these qualities is trustworthiness. When Pete talked about the 'personalities' that the smart watch should possess, he referred to his wife who could help him make the right decision even if it was hard for him to accept at that moment. He therefore designed a strong and firm smart watch. Jason described the *quality* of his bracelet by referring to it as his "best friend" which gives him room to challenge himself. This is reflected by the bracelet giving signals on multiple levels so that he could "search for your [his] own limits." Mary referred to the table lamp as a family member who could read the subtle change of mood in the air and express it empathically. These comparisons (to a spouse, a friend, and a family member) lead us to the interpretation that the designs should be trustworthy so that they could feel safe to share their emotions, ask support from, and to rely on to make the right decisions that benefit them over the long term.

Respectfulness

Another quality is respectfulness. To achieve this quality, the design should take into account users' personal values which drive their actions in dealing with stress. Pete admitted that it might be difficult to accept using the watch since withdrawal from conflicts with others might make him feel weak and give him a sense of failure. Jason said that his military experience had trained him to stick with principles and authority. Any suggestions that compromised these values could be difficult for him to follow. This makes us realise the importance of taking into account the users' personal values to avoid coercion of behaviour or social stigma caused by wearing the product. Mary's design of the table lamp shows respect for personal privacy by not revealing personal feelings in group conversations. Additionally, interpretation can be made that smart wearables should allow for the person's autonomy when making their own decisions. This is exemplified by the bracelet which intended to raise Jason's awareness (through contractions), but was put to sleep by him (by tapping on it twice). According to Jason, the freedom the wearable provided to interact with it, would also be the flexibility that could be used to train coping with stress.

Discreetness

What we learned about interviews is how smart wearables should be discreet regarding their presence in physical and social settings. According to Mary, the table lamp she designed should look like part of the interior so that visitors would not recognize it. The changing colours of light indicate the 'group's' tension, but not that of 'individuals'. These meanings would only be shared within the family. Jason designed the bracelet to silently communicate with him to avoid attention from others. He also chose rubbing and tapping as ways of communicating with the bracelet which are gestures that would not draw too much attention from others.

To summarise, interpretation of experiences of the participants and their visions about future use of smart wearables leads to considerations about their potential partnership qualities of being *trustworthy*, *respectful* and *discreet*. These are constructive elements for building up partnerships with the wearables. The insights show that these qualities can be designed with considerations on people's appreciation of human characters, personal values, life habits, and social environments.

2.5 Discussion

We reflect on how the interpretation of the participants' experiences and envisioned design concepts helped us to substantiate the conceptual framework in terms of sensing, intervention (providing support) and relationships they may establish with smart wearables as partners. We also discuss the design implications on stress management brought about by this design framework and the relevant social and ethical concerns. We conclude the discussion by reflecting on limitations and looking at future work.

2.5.1 Designing smart wearables as partners

Aggregation of multiple sources of data

Our interpretation of the qualitative data implies that stress is a complex phenomenon that requires understanding of the individual as well as the situation. Interpreting the qualitative data also provided us with some initial insights on how to apply wearable technologies to sense some effects of stress, which can be aligned with the work of other researchers in the field. An individual's stress levels can be assessed through physiological and behavioural sensors, such as heart rate sensor, respiration sensor, skin conductance sensor and accelerometer (Choi et al., 2012; Cruz et al., 2012). Tangible user interfaces can be used to enable the person to report his or her subjective feelings of stress in real-time or reflect on its previous occurrences (Guribye et al., 2016; Kusserow et al., 2012). When designing interfaces to report on stress as it occurs, the interaction should fit with the situation and should not disturb the current activity one is engaging in. This has been exemplified by the bracelet designed by Jason.

Situational cues (such as time, location, and one's personal schedule) can be used to indicate particular environments or social situations that might be potentially stressful for a person (i.e., understood as triggers for stress). An integrated perspective on stress and synthesis techniques are required to combine these situational aspects with individual needs, preferences, and preferred coping behaviours. The emerging trend of integrating machine learning in stress detection is a promising way of addressing this issue (Garcia-Ceja et al., 2018). Understanding stress by aggregating various sensing technologies can therefore provide a promising basis for providing support in stress management that suits the person as well as the situation.

Self-tailored, therapeutic and social support

The veterans participating in this study talked about different types of support they preferred to receive in different situations. This included raising awareness, helping them cope with stress by applying their preferred coping strategies, and mobilising social support. In the workshop, participants mentioned how signals produced by wearables could raise their awareness of stress. Jason talked about how contractions with different intensities could serve as stress reminders, Pete referred to alarm sounds and vibrations as warning signals for stress and Mary mentioned colours of light as a kind of 'social tension indicators'. Factors that we believe affected the selection of these signals includes their personal preferences for a particular sensory modality, their correlation to stress levels, and their appropriateness in social situations. Moreover, it can be a challenge to decide which coping strategies are appropriate and how they would work to help the person. The discussion on appropriate coping behaviours is ongoing in the field of psychology and depends on their short-term effects on stress and long-term perspectives towards the individual's development (Thwaites & Freeston, 2005). For example, avoiding stressful social situations can keep the person away from the potential risks in the short term, but could result in him or her becoming isolated from society in the long term. Professional guidance is needed that not only helps the person to decide on suitable coping strategies in the situation, but also benefits him or her for long-term development. Jason specifically suggested sharing the data collected by the bracelet with therapists, which could then be further integrated as part of the therapeutic treatment.

Smart wearables experienced as partners

In this chapter, we suggest designing smart wearables that form a partnership with the wearer. Results of our study provide insights into the experiential qualities of such partners, i.e., *trustworthiness*, *respectfulness* and *discreetness*. Trustworthiness expresses the veterans' wishes that wearables help them to do the right thing at the right time, encourage them to challenge themselves, and to communicate in an empathic way. Respectfulness emphasises that smart wearables should be aware of the users' limits (privacy and personal values) and permit the autonomy to make their own decisions. With discreetness we emphasise the sensitivity of the design to social situations. Reflecting further on the results of the workshop, we formulated additional questions, for example, how the appearance, behaviour and interactivity of the wearable can trigger perceptions, and to what extent the wearable partnerships are distinct from or related to partnerships with the counterparts of humans and animals. We imagine that shaping smart wearables as partners might diverge from designing intelligent computational agents that resemble humans such as social robots and conversational agents (i.e., relying on anthropomorphism). For further inspiration we consider notions of zoomorphism and animism when thinking about expressing the intelligence or agency of smart wearables in alternative ways (Jung et al., 2017; Marenko, 2014; Rozendaal et al., 2019).

2.5.2 Design implications

Our conceptual framework raises some concerns on the implications brought by technological interventions in mental healthcare. In the field of HCI, attention has been paid to the role of interactive artefacts to empower people in behavioural change (Höök et al., 2008; Johnstone, 2007; De Haan et al., 2021; Bruns et al., 2021). This reconciles with the shift of focus in mental healthcare from diagnosis and treatment based on symptoms, to preventive interventions based on risk assessment (Tartarisco et al., 2012). Our study provides a specific context of designing for everyday stress, in which particular perspectives and design strategies need to be developed. Specifically, our approach calls for a design direction that empowers individuals with sensitivity and knowledge to identify and deal with their mental issues on a daily basis. It also provides an overall perspective to view the current development of eHealth interventions for mental health in forms of mobile or wearable applications (Luxton et al., 2011; Morland et al., 2017).

We also recognize some ethical concerns. This is reflected in personal differences in interpreting stress notifications and interventions and the different levels of authority and autonomy requested by the participants when it comes to making decisions and taking action. For example, Pete preferred strong and loud signals that could bring him back to reality, while Jason chose a private and flexible manner to communicate with the bracelet. This raises the question to which extent we should allow for (wearable) technologies to take the initiative. Concerns might arise that too great a reliance on these technologies could undermine the person's resilience and ability to deal with stress. Therefore, we should make sure that we design smart wearables that are responsible and value-sensitive to help people as they want and within limits of their capabilities (Friedman & Hendry, 2019; Van den Hoven, 2013).

2.5.3 Limitations and future work

This study provided anecdotal materials of three participants to substantiate a conceptual framework on smart wearables as partners to help veterans with chronic PTSD to deal with stress. In qualitative research, small sample sizes are common when investigating individuals' first-hand experiences. However, larger groups of participants are required to assess how smart wearables as partners would have an impact on stress management. Such a final evaluation has fallen outside the scope of this thesis because—given the complexity of the research phenomenon—more fundamental questions needed to be answered first. At this stage of the research, it could also not be assessed to what extent smart wearables as partners may be actually realised on the basis of these technologies. Some of these fundamental questions have been the focus of studies performed later in the research. In particular, Chapter 4 reports on exploring the performance of sensor technologies in fabrics and garments while Chapter 5 reports on challenges related to the further integration of these technologies into an interactive prototype.

We would like to conclude this section with some remarks about involving participants with a stress-related mental disorder in participatory research. The study was planned and conducted to give participants a voice considering the sensitivity of the topic. For example, in the co-design workshop, three students were involved in the workshop to assist the participants in the creation process. In the process, we noted that sharing daily life experience by means of vlogs might be technically challenging for some participants. Jack, who dropped out of the study before the workshop, stated that it was difficult for him to think about what to film if there were no strict rules. Thus, future work should also consider participants' expertise and particular life situations, and whether they are comfortable with the research tools to be used.

2.6 Conclusion

This chapter presents a qualitative study and a co-design workshop with three veterans with chronic PTSD to explore the possibility of designing smart wearables as *partners* to help them deal with stress in everyday contexts. The materials presented in this chapter helped us to substantiate our conceptual framework on smart wearables as partners for this target group. We learned about the opportunities for smart wearables to be able to understand stress in a more nuanced way than current state-of-the-art systems by synthesising physiological sensor data on stress, feedback on how a person experiences stress, and data sources that might shed light on the contextual triggers of stress. We learned that smart wearables should provide different types of support given differences in personality and coping styles, and the kind and type of stress experienced. In addition, the results of the co-design workshop helped us to identify partnership qualities, i.e., *trustworthiness*, *respectfulness*, and *discreetness,* that can promote the use of smart wearables as partners and that can help wearers to build up a relationship with them over time. Reflection on results of this chapter led to a discussion on the design implications of the applications in mental healthcare, and on ethical concerns that come with it. Learnings from this chapter formed the conceptual foundation for the follow-up studies aimed at researching how such wearable partners could be *expressed* in the interaction (Chapter 3), *realised* by employing digital and physical materials (Chapter 4 and 5), and *experienced* by people who wear them in real life (Chapter 6).

Acknowledgment

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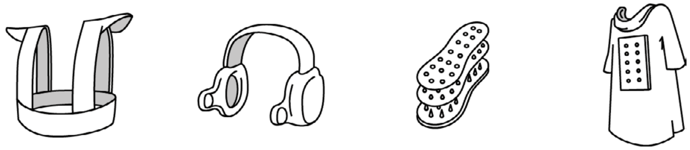
CHAPTER 3

Towards a Vocabulary to Shape Smart Wearables as Partners



This chapter is adapted based on a manuscript submitted to the journal of Wearable Technologies.

In this chapter we engage in speculative design and enactments with the aim to understand how partnerships with smart wearables can be *expressed*. Our reflection on the speculative designs crafted and enacted by design students in a workshop led to the understanding of wearable partners as *organs*, *collaborators* and *mentors*, which can be referred to as three *genres* of human-wearable partnerships, each exhibiting particular physical and temporal forms and ways of affording interaction. We discuss how these genres are conceptually distinct and could coexist in use. Furthermore, we reflect on how our work is aligned with postphenomenological theories and frameworks on human-wearable relations, and relates to the fields of somaesthetics, human-agent interaction, and persuasive technologies for mental health. We use the vocabulary of the three genres in the next chapter in which the concept of wearable partners is explored on the level of design realisation.

3.1 Introduction

With the advances in wearable sensors and computer technologies, smart wearables are increasingly used to help people manage stress. However, wearable devices are often designed as tools for the detection and representation of stress-related signals. In such cases, wearers are informed of their stress but are left to deal with it by themselves. To address this issue, we aimed to develop knowledge to guide designers to design smart wearables *as partners* that take on a more active role to help people cope with stress.

In this chapter, we focus on the form factors that contribute to the partnerships with smart wearables in the context of stress management. In particular, we refer to the work on the formgiving perspective in HCI where researchers (Robles & Wiberg, 2010; Vallgårda, 2014; Wiberg, 2014) consider computation as a type of digital materials which can be crafted together with physical ones to shape interactive artefacts as experienced wholes.

In this chapter, we aim to provide a design vocabulary to help designers give form to smart wearables as partners. We discuss the current applications and design opportunities of smart wearables for stress management. We elaborate on the notion of partnership and formgiving approaches in HCI, which provide *a material lens* to look into the potential of smart wearables to be shaped as partners. We report on a one-day workshop where nine industrial design students were asked to create low-fidelity mockups of smart wearables to investigate their materiality, interactions and meanings as an initial exploration of the design space opened up by the conceptual framework presented in Chapter 2. Interpretation of the students' work helped us to formulate a vocabulary to describe how partnerships with smart wearables can be expressed across three 'genres'. Furthermore, we discuss, with the help of the vocabulary, how the three genres relate to, and are different from, a postphenomenological understanding of human-wearable relations. The chapter is concluded by a discussion of the contributions of the genres and the vocabulary to the fields of HCI and Artificial Intelligence and provides directions for future research.

3.2 Related work

3.2.1 Understanding stress

Stress is a phenomenon that involves physiological and psychological processes. The mechanism of stress can be explained by “the fight and flight response”; the autonomic nervous system unconsciously and immediately regulates changes in hormones and physiological vitals such as heart rate and respiration to prepare the person to fight or flee a perceived harmful event, attack or threat (Jansen et al., 1995; Lovallo, 2015). From a psychological point of view, stress is considered to be a process in which the person perceives a potential threat from the environment that takes mental and behavioural efforts to deal with (Folkman & Lazarus, 1984). On the other hand, note that positive stress (known as *eustress*) triggers the person to feel happy and motivates the person (Bienertova-Vasku et al., 2020). For example, the pressure of an approaching deadline helps the person finish the work at hand more quickly and enjoy the sense of achievement afterwards. The boundary between positive and negative stress remains blurry, as the same stressor can cause different stress reactions in different individuals, and even in the same person in different situations (Hargrove, 2013). In this paper we focus on negative stress (distress), especially stress triggered by everyday situations (daily hassles), which is relatively temporary and mild compared to chronic posttraumatic stress disorder (PTSD).

3.2.2 Smart wearables for stress management

Smart wearables are integrated wearable devices or garments composed of sensors and actuators, data processing units, (wireless) connectivity, and power supplies (Chan et al., 2012). A range of wearable devices have been designed to help people deal with stress. By being directly worn on the body or being in close proximity to it, smart wearables can detect stress based on a range of physiological and behavioural signals and can provide support by providing tactile actuation or other ways of communication that are both intimate and private. Furthermore, by being closely present and co-witnessing a range of different situations over time, smart wearables can access data that helps assess how someone deals with stress over time, thereby opening up the possibility of providing tailored support.

A variety of sensors are available to sense stress-related biomarkers, for example, heart rate variability, skin conductance, and respiratory rate (Choi et al., 2012). With the use of advanced algorithms, stress can be predicted even before it occurs (Garcia-Ceja et al., 2018). Researchers also attempt to detect stress through one's behavioural characteristics such as voice (Lu et al., 2012), facial expressions (Gao et al., 2014), and body movements and gestures (Carneiro et al., 2012; Sun et al., 2012). Other researchers have studied the relevance of contextual information to stress, such as locations where stressful events occur (Burns et al., 2011), activities on social media (Lin et al., 2017), and use of smartphone applications (Ferdous et al., 2015; Wang et al., 2014). In addition, we found wearable applications (especially smartphone and smartwatch applications) that enable people to report their own stress in forms of tags, scales and digital diaries (Adams et al., 2014; Almeida, 2005; Intille et al., 2003).

Smart wearables are also used to help people in stress-coping activities. Some applications aim to increase stress awareness by means of *just-in-time* notifications. For example, Cruz et al. (2015) developed a wearable system composed of physiological sensors and a smartphone application to help the person manage stress prior to a panic attack. Some applications, such as apps developed for Fitbit and Apple Watch, employ real-time biofeedback to guide people in relaxation exercises. In addition, we also found applications that engage people to reflect on causes of stress and to develop positive ways of coping with it. For example, Sanches et al. (2010) developed a wearable system that could translate bio-sensed signals into abstract visualisations to trigger users to reflect on their previous emotions and stress experiences. MacLean et al. (2013) designed MoodWings, an artificial butterfly worn on the wrist that could react to the wearer's stress status by opening and closing its wings. Another example is Catch It (Kinderman et al., 2016), a smartphone application that provides tailored psychological support based on self-evaluation and basic principles of cognitive behaviour therapy (CBT).

The increasing computational capabilities and how they can be integrated in wearable systems open up a design space that we will explore with the concept of smart wearables as *partners*. Despite the variety of methods to detect stress and provide interventions, wearable products are often applied as tools for detection and representation of sensed stress-related data. We see an opportunity of designing smart wearable systems that could engage human wearers in a more balanced and mutual relationship, i.e. partnerships. Below we elaborate the motivation of designing smart wearables as partners (also see Chapter 1 for an overview of this motivation).

3.2.3 Human-computer partnerships

In HCI, the notion of partnership is used to refer to a collaborative relationship between computers and human operators. Discussion of computers as partners emerge from the recognition that everyday physical objects, including wearable ones, are becoming ‘smarter’ by their embedded computation and electronic communication capabilities. It is possible to start thinking of these objects as “collaborative partners” that make sense of the physical world, can reason about it, and act within it (Rozendaal et al., 2019). To design these partners, more attention is being paid to the interdependencies and collaborations that may exist between humans and computational products. Jacucci et al. (2015) proposed a *symbiotic relationship* in which both the humans and computational partners retain their own goals and agency. They proposed that such computational partners should be able to understand users’ needs, goals and preferences, and provide proactive support even before people have explicitly requested it. Jaccuci et al’s (2015) work implies an active role that can be played by the computers that go beyond digital or robotic servants that only follow orders of human users.

Design strategies to shape computational artefacts as partners vary in the use of a grounding metaphor. For instance, computers may express their intelligence and agency by mimicking humans. Examples of this are social robots or voice assistants (also known as *conversational agents*) designed to express human body movements, facial expressions and the use of natural language (Looije et al., 2010; Luria et al., 2019). However, people may attribute life-like characters to computational products that are obviously not in the shape of, or behave like living beings. Janlert and Stolterman (1997) talk about how the character things are gestalts consisting of multiple product attributes that together can create a coherent product personality, which may have anthropomorphic connotations. With the notion of *animistic design*, Marenko and Allen (2016) suggest that designers explore the uncertainty and unpredictability of digital artefacts as sources of inspiration by giving them intention, behaviour and personality. Rozendaal et al. (2019) proposed “Objects with Intent” (OwI’s) as emerging types of artificial agents (Dennett, 1987; Jennings & Wooldridge, 1995) that take advantage of the meaning of everyday things as the site for their intelligence and agency, with familiar uses, anticipated contexts of use, and known ways of interaction. For a treatise on agency of humans and of artificial agents, see e.g., van de Poel, 2020. These works inspired us to focus on the *expression* of human-computer partnerships that emerge from their materiality and use.

Designing smart wearables as partners requires paying attention to the interactions they afford and the contexts within which these interactions are situated. First, wearable products are often used by people who are on the move or engaged in other activities. Therefore, designers tend to limit the information communicated by the wearable and reduce the effort required from wearers to interact. For example, wrist-worn devices often use short vibrations to attract the wearer’s attention without requiring a response (Motti, 2020). In addition, interactions with wearable products can involve the human body as part of the interface. For example, wearable products can involve users by asking them to provide input through gestures and postures (e.g., Moschetti et al., 2016) and communicate with wearers by using vibration and temperature (Zeagler, 2017). Finally, we should note the social influence of wearing and interacting with wearables. Wearable products such as clothing and accessories represent the wearer's self-perceived image and pursuit of social status and acceptance (Anderson & Lee, 2008; Yang et al., 2016). These features make smart wearables a unique type of computational partner in how they can engage a person in a dialogue and provide support. However, designing smart wearables as partners is a concept that warrants exploration of the possible interactions with it, the technologies to realise the design and the experience interacting with it.

As the first step in this direction, Chapter 2 discusses the idea of designing smart wearables as partners in the context of stress management of veterans who suffer from chronic Posttraumatic Stress Disorder (PTSD). The qualitative study and codesign workshop with three war veterans with chronic PTSD presented in Chapter 2 provided initial insights to approach the concept of smart wearables as partners. For instance, we explored how smart wearables could be capable of gaining a nuanced understanding of stress based on a variety of data sources, including physiological, behavioural, subjective, and contextual ones. We discussed how smart wearable partners should provide appropriate kinds of assistance and support based on learning about the individual and the situation. Based on our interpretation of participants' descriptions, we argue that *trustworthiness*, *respectfulness* and *discreetness* are important qualities to enable partnerships with smart wearables. In this chapter, we take this conceptual proposition a step further by looking into how designers can shape the *expressiveness* of such partners by crafting their physical form, temporal form and ways in which they could engage people in interaction.

3.2.4 Giving form to smart wearables as partners

Industrial Design has a long tradition of understanding form factors or products and how they are shaped in design practice (Vormgeving in Dutch, Gestaltung in German, or Formgiving in English). In HCI, researchers have taken up a formgiving perspective that considers computers as digital-physical materials in shaping interactive artefacts as experienced wholes (Robles & Wiberg, 2010; Wiberg & Robles, 2010), which according to Hallnäs and Redström (2002) provide interactive artefacts with the expressiveness that makes them meaningful. This understanding requires designers to be sensitive about not only the properties of physical materials that help shape the appearance of the product, but also the computational capabilities that enable its behaviour, which in combination with the physical material afford interaction. Vallgårda (2014) elaborated on these three form elements in interaction design: the physical form (how the things appear), the temporal form (how the things behave) and the interaction gestalt (how the things afford interaction, i.e. their interactivity). Vallgårda's (2014) framework can help us to understand how to meaningfully shape smart wearables as partners; it provides a means to describe the ways in which physical materials and computation can be crafted to promote the expression of partnerships with the wearers in the interaction. See Figure 3.1 for an overview of and the relations between the three elements. Below we explain definitions of these form elements based on Vallgårda's (2014) description and reflect on how they relate to the design of smart wearables.

Physical form refers to the tangible aspects of objects and includes the physical properties of materials such as their weight or size, as well as intangible aspects such as temperature and the audiovisual effects they produce (Vallgårda, 2014). We understand the physical form as the appearance of objects as they appear to people through their perceived consistent and stable set of characteristics. When reflecting on the physical form of smart wearables, this includes considering the selection of the electronic components (sensors, actuators, processing units, etc.) and how they become integrated in the materials (e.g. fabrics) and modalities (e.g. garments). Tactile experiences often take a prominent role since they are worn, carried or held close to the body. Another particular quality of smart wearables is how they might not be visible to the wearer when worn near the face or back, or when hidden underneath clothes. Furthermore, smart wearables might be experienced radically differently by the wearer compared to other observers who *see* it because the (private) tactile experiences smart wearables may provide remain elusive to them.

Temporal form refers to the pattern of the state changes that the computer will produce (Vallgårda, 2014). When viewed in this way, software programming inherently becomes a formgiving practice. We understand the temporal form as the behaviour of objects since they are perceived as motion, and expressions of goal-oriented behaviour. By taking example of the notion of the *state-machine* in computer programming, a software program can exist in particular *states* that are linked to the performance of particular *functions*. A software program can move across states when particular 'conditions' have been met. These changing states need to have an expression for people to pick-up on and the extent to which they can interpret the meanings behind the information. An object's temporal form is dependent on its physical form because any transformation must be expressed in some kind of medium, being physical, digital or a mix of the two. Because of the close proximity smart wearables have to the human body, their behaviour can be easily experienced as annoying or disturbing, and therefore need to be considered carefully.

The interaction gestalt refers to the action or movement of the user in relation to the object, and vice-versa, how the object moves and responds in relation to the user (Lim et al., 2007; Vallgårda, 2014). Similar to Gibson's (1986) notion of affordance, interaction gestalt suggests an active role of users in defining the use of the products. In this context, Hallnäs and Redström (2002) stated that "the expression of things in use seems to define functionality just as much as functionality seems to explain design expressions" (pp. 106). With interfaces of wearable products shifting from visual displays to physical interaction, Nunez-Pacheco and Loke (2014) and Motti (2020) argued exploiting the non-verbal body language shared by both the wearable product and the human user, which requires little effort from users and draws little attention from others. For example, some smart watches use 'tapping' as a simple gesture to start up the device.

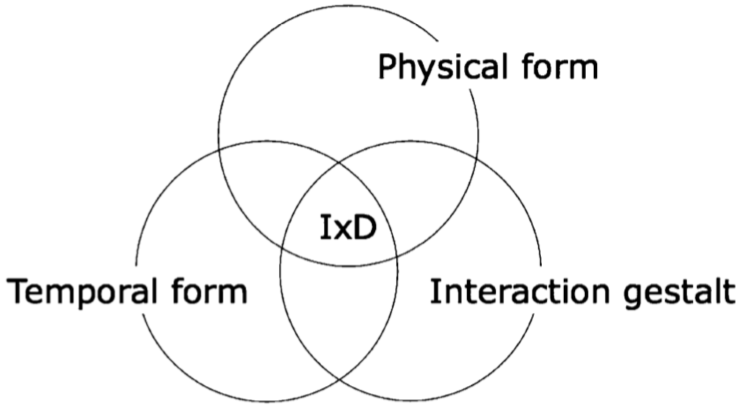


Figure 3.1. Illustration of the three form elements of interaction design (I x D) (Vallgårda, 2014).

3.3 Design workshop

To inspire our idea of smart wearable partners, we conducted a one-day design workshop to explore *how partnerships can be expressed through interaction with smart wearables* by paying close attention to how participants used physical materials to embody these wearables and how the computation and interactions they afforded could be enacted in narrated performances. Design students rather than veterans with chronic PTSD were involved in the workshop because of its speculative nature and the design sensitivities that are required to explore the expressiveness of smart wearable partners concerning their form, interaction and meaning. In interpreting these speculative artefacts and design enactments, we refer to Vallgårda's (2014) formgiving framework of interaction design.

3.3.1 Participants

We recruited nine first-year Master students of Industrial Design (2 male, 7 female) studying at Delft University of Technology. The workshop was held in a spacious dance studio at a student cultural centre that provided room for participants to freely move around and to craft their mock-ups with the tools and materials provided. The workshop was a part of a selective program given by the faculty of Industrial Design Engineering (IDE) which consists of a series of full-day workshops aiming to help design students gain transferable skills and a basic knowledge of design. The students were recruited voluntarily through an online poster. None reported having stress-related mental issues. As explained in the poster, they were involved as novice designers to learn about using their own bodily experiences as design resources to design tangible interaction with smart wearables.

3.3.2 Workshop procedure

The workshop consists of five parts, namely *Briefing*, *Sensitivity training*, *Designing*, *Narrated performance*, and *Group discussion*.

Briefing

At the beginning, we introduced the technical aspects of wearables and how such technologies could be used to sense stress and provide interventions in stress management. We described stress as both a physiological reaction and psychological process, where a person takes mental and behavioural efforts to deal with environmental demands that exceed the person's perceived resources (Folkman & Lazarus, 1984). The specific definition of wearable partners was not explicitly given to the students. Instead, we briefly translated this concept into a design brief that asked students to design smart wearables "that present different *expressions*, and take the *initiative* to engage people in *negotiations* to help people deal with stress" (adapted from the notion of wearable partners in Section 2.2 of Chapter 2; the setup of the workshop can be found in Appendix 2). In particular, we asked them to explore how smart wearables can be designed to express a sensitivity to people's feelings and circumstances, and how they can act to provide support in appropriate ways, in-the-moment as well as over longer periods. Furthermore, we asked them to focus on non-verbal bodily interaction when considering the interaction with wearable technology.

Sensitivity training

We used improvisation theatre techniques (Besseling, 2002) and techniques in *somaesthetic design* (Jung & Ståhl, 2018) to help the students become more sensitive to their own bodily experiences and use these experiences as a resource in design. For example, to experience how emotions are expressed, we asked them to act out a range of positive and negative emotions in small and subtle to large and exaggerated ways. Probing questions were asked to help them reflect on how these emotions corresponded with particular bodily postures and movements. To help prepare the participants for the dynamics involved in human-wearable interaction, they were teamed up in pairs and asked to copy each other's movements in *mirroring exercises*. These made them more sensitive to aspects of initiative and control but also helped them experience interactions as emerging in situations when both parties have influence. Finally, to prepare participants for enacting interactions with smart wearables in specific situations, we asked them to *enact* peoples' behaviours in a fictional setting of a zoo where they needed to carefully observe the actions of others and collaborate with each other to co-create imaginary scenes.

Designing

After these sessions, participants worked in four groups of two or three to envision concepts for smart wearables that help people deal with stress. They were asked to articulate how their wearables could help a person deal with stress in particular situations. We provided them with pens and large sheets of paper to help them sketch and think through the design by making annotations. We also provided tinkering materials (such as fabrics, scrap, straps, Velcro, scissors and tape) which they could use to realise their concepts in low-fidelity mock-ups. In a rapid design process where participants iterated between making, enacting and reflecting on their design ideas, they were able to articulate their final concepts.

Narrated performance

The students presented their work using role-playing techniques with the help of the low-fidelity mock-ups. Role-playing, as a particular kind of experience prototyping technique, is commonly used by interaction designers to promote creation of design concepts, especially when the technologies are not ready for the designers to directly use or implement in real life (Barati et al., 2017; Buchenau & Suri, 2000; Svanaes & Seland, 2004). We adopted this method in this workshop to encourage the students to directly use experiential insights gained from the section of *Sensitivity Training* and the mock-ups made in the *Designing* session. Each group staged the final enactment of their concept in a narrated performance before the other students as the audience. Performing participants were assigned three roles: an *actor* who interacted with the product, a *Wizard of Oz* who mimicked the movements of the wearables (as an expression of their computation), and a *narrator* who narrated the story for the audience. In cases where a group consisted of two students, the wizard and narrator were played by the same person. After the performance, the audience could ask questions for clarification which led to discussions that helped us understand the details of the design concepts and possible alternatives to be envisioned collectively. Their performances were filmed for later reference and analysis.

Group discussion

After all the concepts were presented and critiqued, participants gathered together in a group discussion and reflected on their experiences of the workshop. The participants elaborated on their experiences as designers as well as on their experiences as users of their own designs in relation to what they liked and did not like about the wearables' sensitivity and applicability. These conversations caused particular design issues to surface, such as the intuitiveness of the interaction, mechanisms of persuasion and support, as well as ethical and normative aspects of the designs. These group conversations were audio-recorded and transcribed for further analysis.

3.3.3 Design Concepts

In the workshop, the participants produced four concepts of smart wearables to help people deal with stress in particular situations. The aim of this speculative design exercise was to explore the expressiveness of smart wearables as partners and not for conceiving viable design solutions as real-world applications. The students did not study the literature on the chosen problems, to find existing designs, and critiques to those designs. Given this purpose and the limited time available to work out their concepts, the results are rather naive, demonstrating little depth in their application. However, they do demonstrate various perspectives on aspects of form, interaction and meaning. The design concepts are elaborated in the next sections based on the mock-ups themselves and how participants enacted and presented them. Figure 3.2 gives an overview of the mock-ups, enactments and a scene from the narrated performances.

A vest that presses the shoulders and straightens the back

One group designed a vest that can help people adjust their posture and relax their shoulders to calm down in stressful situations. They enacted a scenario where a vest helped a blind person (with the fictional name of Sarah) while she was travelling by train. As the vest could sense the rising tension of the wearer by detecting a change in posture and breathing rhythm (triggered by the anxiety of nearing the next stop to change trains or when entering a busy train station), the straps around the person's shoulders would be tightened to remind Sarah to straighten her back to feel more confident. In addition, the straps could also apply continuous rhythmic pressure on the shoulders to entice Sara to do a relaxing shoulder-exercise.

A pair of headphones that massages the temples and force the person to take a break

The second group envisioned a pair of headphones that help a student who is working on a deadline to relax, and ask him to take a break. When sensing an increase in a wearer's stress via the pulse sensor integrated in the headphones, the headphones start to play peaceful music and provide massage-like vibrations on the person's temples, located just above the ear. If a person's stress continues to increase despite the music and massaging vibrations, the headphones, which are connected to the laptop, lock the computer screen with a message displayed saying "please come back in 5 minutes". The student has no other choice but to take a break.

A shoe that stings the foot while driving

The third group designed a pair of shoes that promote safe driving for novice drivers during a driving lesson. The sole of the right shoe, used for controlling the gas and the brake pedals, can sense the stress of the driver and change texture. Depending on the wearer's stress levels and the particular driving situation, the sole of the shoe can change from soft, to harder, or to pointy textures as the level of stress increases (see Figure 3.2). By feeling these changes through the bottom of the foot, the driver becomes more aware of stress and is reminded to drive more calmly. A sudden peak in stress (for instance caused by an emergency situation) will cause the sole of the shoe to spike, causing a sting that makes the driver instinctively lift his foot from the gas pedal. The idea is that this would help prevent an accident.

A night robe that moves on the back

The fourth group explored the concept of a night robe to help a single mother attend to her newborn baby during the night. The night robe is equipped with two rows of balls on the back of the garment that can be actuated depending on the level of the mother's stress. These balls can *push* against the person's back as a way to gently get her out of bed and encourage her to move towards her baby, *rub* the back by providing alternate rolling-actions of the balls to comfort her, and *stroke* her back with a downward motion to prompt her to sit down with her baby. The robe, with the different actuations it provides, is intended to support the mother to take actions to take care of the baby but also to help her relax in such a stressful situation.

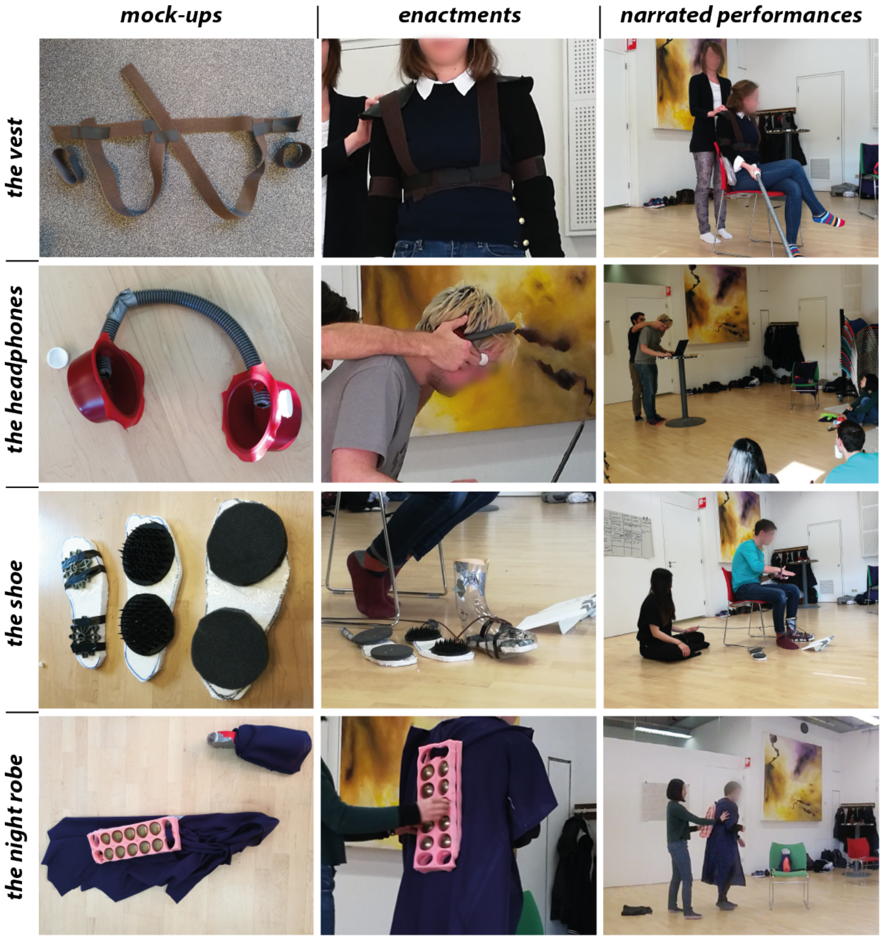


Figure 3.2. Design mock-ups, enactments and narrated performance. Top to bottom: a vest that presses the shoulders and straightens the back; a headphone that massages the temples and forces the person to take a break; a shoe that stings the foot while driving; a night robe that moves on the back. Left to Right: details of the mock-ups; design enactments worn by the actors; one scene from the narrated performances where the wizards were mimicking actuations of the mock-ups.

3.3.4 Data analysis

Data collected from the workshop includes the physical mock-ups made by the participants, videos of the narrated performances (design enactments), and transcripts of the group discussion. The research group, composed of the PhD researcher and the PhD supervisory team, reflected on the students' work using Vallgårda's (2014) framework as an interpretive lens. In particular, we aimed to find out how different types of partnerships are expressed in terms of their physical forms, temporal forms and interactive gestalt. Reflection on the *physical forms* of the design examples involves the use of physical materials in the overall composition, material qualities, and participants' description of what the smart wearable looked like or how it felt on the body. To understand the expressiveness of the designs in terms of their *temporal form*, we focused on the movements as they were enacted by the participants and paid attention to how the students explained the ways in which the smart wearable could move or how it could react to the wearer's actions. To understand the different types of *interaction gestalt* between the wearables and the wearers, we reflected on how the designs could respond to actions of the wearers and vice versa, how the persons could respond to actions of the smart wearables.

3.4 Identified genres

From the design examples provided by the students, we identified three genres to categorise the *expression* of wearable partners in terms of their physical form, temporal form and interaction gestalt. We explicitly use the term *genre* because it addresses how a multiplicity of individually expressive features can collectively be experienced as belonging to a particular class or identity. Frow (2013) describes the use of genre in cinema, music, food and fashion, and highlights how genres combine multiple sensory domains and multiple modes of expression. In our own interpretation guided by Vallgårda's (2014) framework, each genre includes a set of adjectives that describe smart wearables as *organs*, *collaborators* and *mentors* across their physical form, temporal form and interaction gestalt (see Table 3.1). We present each genre by first defining it and then illustrating how this definition is anchored in the design concepts.

Table 3.1. Vocabularies for the formgiving practice of smart wearables as partners.

Genres	Physical form	Temporal form	Interaction gestalt
Organs	Translational	Ephemeral	Reflexive
Collaborators	Intentional	Procedural	Negotiable
Mentors	Sentient	Maturing	Co-developing

3.4.1 Organs

We introduce the term *organ* to describe smart wearables that can *translate* sensor readings from the body and the environment to observable signals that can help the wearer to become aware of their behaviour (in our case become aware of stress), and to reflexively react to these situations in an appropriate way. The inspiration comes from natural organs in the bodies of humans. For example, consider how the stomach signals (by cramping) that the person eats something wrong or too much, or the skin creating goose bumps and starts shivering when the person is in a cold environment for too long. For dealing with stress, this means that a smart wearable functioning as an organ can translate stress-related signals (such as heart rate, skin conductance and temperature) into observable signals (i.e., pressure, movement, media) which can help the wearer be aware of stress and deal with it *reflexively*. They behave *ephemerally* in response to fluctuating bodily changes caused by stress. The interaction with such wearables is *reflexive,* which allows a person to intuitively manage stress, and by doing so, can become more aware of it. Organs are thus simple devices that measure bodily signals and display them to the wearers.

In terms of their physical form, smart wearables are *translational* because they translate stress-related signals into other sensory modalities. We noticed how the placement of the wearable on the body was critical to making this translation meaningful (i.e., placing a smart wearable on the body where stress is felt and expressed but also considering a logical site of intervening through actuations). For example, the design of the vest was inspired by the tendency of people to raise their shoulders when they are stressed and how a shoulder massage could help release it. Similarly, the design of the headphones was chosen not only due to the music that could be heard through it, but also as being able to rub the temples (just above the ears) through vibrotactile stimulation, something people tend to do naturally when they feel stressed. Furthermore, the *affective tone* of these signals was also found to be critical in communication. In the examples of the vest, headphones and the robe, the actuations of the smart wearable led to pleasant massage-like experiences, which were referred to as useful relaxation techniques. However, actuations of smart wearables that cause an unpleasant experience also had their use. For instance, the textural differences of the sole of the shoe had the purpose of making the novice driver become aware of his stress status while driving, or making the driver instinctively take his foot off the gas pedal in case of an emergency.

In terms of a wearable's temporal form, smart wearables as organs are *ephemeral*. This means that the smart wearable—being a translational device—acts as an immediate response to a person's varying stress levels. To revisit the example mentioned above, the vest being sensitive to tension changes in Sarah's neck-muscles adjusted the speed and strength of the strap contractions to provide a massage-like experience by adding up pressure when the smart wearable sensed that Sarah raised her shoulders and decreasing pressure when they were lowered. Similarly, participants working on the shoe emphasised how the texture-change of the sole should be accurate and should respond immediately to changes in the driver's stress-level. In this way, the smart wearable can inform the driver of his or her stress subtly without disturbing the performance of the driver or be more dominant in the communication when there is a need to. An interesting discussion point here is how the translation in terms of timing creates a connection with the felt stress, for instance by gently augmenting the bodily felt experience with other signals, and by exemplifying these signals or modulating their affective tone as described above.

When reflecting on the interaction gestalt, we learned how smart wearables as organs enable a *reflexive* kind of interaction; the wearable responds to the body signals of the wearer and the wearer's body instinctively responds to the actuations of the wearable. Interacting with smart wearables in this way helps people become aware of their stress and manage it by learning new kinds of behaviour without needing to overthink it. We illustrate this with an excerpt from the narrative about Sarah, the wearer of the vest, who was blind and felt stressed in a crowded train station. It relates how the interaction with the smart vest unfolded in a reflexive and intuitive way, as we observed in the enactment of the students:

> *Sarah entered the train station and tried to find the stairs to the platform. People were passing by with noise emerging from the crowd. She didn't know where to go. Slowly her stress level began to rise. She paused and stood still in the middle of the crowd. The vest started to slowly increase pressure on her shoulders. As a response, she straightened her back and took some deep breaths. This gave her confidence and made her focus on the present. She carried on with her steps...*

Another example is provided for the shoe scenario where the participants discussed a novice driver taking a driving exam:

> *The driver was driving a car with the instructor sitting beside him. Suddenly a cyclist appeared in front of the car. The instructor screamed "watch out!". The driver's stress suddenly rose and the sole of the right shoe changed into a rigid texture, giving him a shock at the bottom of his foot. He took his foot off the gas pedal and stepped on the brake to stop the car…*

These two examples show how reflexive interaction with smart wearables is with regard to the ephemeral stress-related information provided by the wearable, but also how people can—based on this information—intuitively respond to it without requiring extensive instruction or training beforehand. An interesting question that emerges here is how to select sensorial signals that intuitively connect to a person's stress experiences, and what kinds of intuitive body movements can be triggered by such signals. Another point for reflection is that interaction with wearable organs happens at a subliminal level. The challenge for designers is how to capture people's attention in subtle yet noticeable ways.

3.4.2 Collaborators

We use the term *collaborator* to describe smart wearables that allow the wearer to deal with their behavioural issues (in our case dealing with stress), as the name suggests, in a collaborative way. Such wearables should be explicit in their *intention* in how to engage people in a collaborative activity. Smart wearables as collaborators act *procedurally* by engaging with a person in a sequence of actions with a clear beginning and end. Interactions with these wearables are *negotiable* as the wearer should feel free to follow the guidance given by the wearable or take the lead in the collaborative activity. Compared to organs that react immediately to sensed bodily signals with a signal that can be subconsciously reacted to by the wearer, collaborators have the added functionality that they can also interact with the user on the deliberative level: the user would be consciously thinking about it.

In terms of their physical form, smart wearables as collaborators are explicit about their *intentions* to engage people in a collaborative activity. Students of the workshop thought about how different actuations of the wearables could instruct and actively guide people to cope with stressful situations. In their designs we recognized how such directionality and the force of these actuations could encourage, nudge, or persuade people to act in particular ways. For example, in the design of the night robe, the balls installed on the back could make *pushing* movements and *downward-stroking* movements to guide the mother to get out of bed at night and sit down to take care of her baby. This following excerpt describes a scene of the design enactment:

> *Noticing her baby crying, the single mom did not get up immediately but still sat on the bed. She looked tired and depressed (with her head down). She put on the night robe. The balls embedded on the back of the robe started to bump up (mimicked by the wizard pushing those balls one by one), and pushed her to get up and go to her baby.*

In the example of the headphones, they could suggest that the student take a rest through the music and vibrations but could also force the person to take a break by shutting down the computer screen. Different from smart wearables as organs, smart wearables as collaborators act to trigger a person to perform a particular sequence of actions, or to stop them from happening.

With regards to their temporal form, smart wearables as collaborators are *procedural* because they are able to engage the person in dialogues to achieve their goals. This is different from the ephemeral behaviour of smart wearables as organs in response to ongoing bodily processes correlating with stress. A procedural temporality is understood as having a starting point (initiated by the wearable noticing a *problem*), a middle sequence (the wearable carrying out a sequence of actions) and end-point (informed by a desired state of affairs corresponding to its intent). For example, in the case of the headphones, the object initiates a sequence of actions when it senses stress via the pulse sensor (i.e., the *starting point*). It then carries out a range of actions to reach the *end-point* (i.e., massaging the temples, playing relaxing music, and as a last resort, shutting down the computer screen). The challenge in designing the smart wearables in this way is to define these process-milestones and to search for the events that allow the wearable to change state.

Interaction with smart wearables as collaborators is *negotiable*. The intention and inner programming that allow the wearable to initiate and sustain particular actions and terminate those actions can be influenced by the wearer in a continuous dialogue or feedback loop. This is especially visible in the design of the vest in a scenario where the wearer *worked together* with the vest in a relaxation exercise. Although the design concept presented by the participants in the workshop is rather naive, its scenario illustrates the interaction and its intended effect:

> *Sarah got on the train and sat down. She began to worry about how she was going to get off and what to do at the next station. This made her stressed. The vest sensed this and started to massage her shoulders slowly and gently. Sarah responded by moving around her shoulders in a certain rhythm. The vest was also able to sense her motions and adapted the rhythm of its movement, while continuously checking whether Sarah was calmed by it.*

These examples illustrate how smart wearables as collaborators can engage the wearer in collaborative activities through explicitly expressed *intentions*, *procedural* guidance and interaction that allows for *negotiation* between wearable products and users. Using smart wearables as collaborators raises interesting ethical questions about whether their intentional behaviour and the negotiations that are possible should be based on an *agreement* between the user and the wearable beforehand, or whether it should develop during use. It also raises more general concerns about who takes the initiative and who is in control, which we will return to in the discussion section.

3.4.3 Mentors

A *mentor*, according to Merriam-Webster is "someone who teaches or gives help and advice to a less experienced and often younger person". We use the term mentor to describe smart wearables that have the wisdom and the sensitivity to teach their mentees, and are able to learn from previous interactions and can therefore show flexibility in the support they provide. To describe these aspects we introduce three aspects in our vocabulary: *sentience*, *maturing* and *co-developing*. We call smart wearables as mentors being *sentient*, by which we mean the wisdom and sensitivity they need to guide their mentees. The wisdom pertains to the knowledge about the topic of mentoring, in our case that would be the knowledge of coping with stress, and the sensitivity refers to the emotional intelligence to bring that knowledge to the mentee in ways that fit their needs and capabilities. We use the concept *maturing* to indicate the capacity to mature over time. This learning capacity refers to learning from the experience of mentoring any individual mentee, but also learning from having mentored many mentees to extract successful patterns of interaction with respect to certain characteristics of the mentees. In terms of machine learning, mentoring many mentees provides the data to apply clustering and pattern recognition techniques. We say a mentor can initiate a *co-development* process in which the mentor and mentee together learn what the best way for the mentee to learn about the topic of mentoring, in our case about dealing with stress. The mentee (the wearer) could learn about their own ways of experiencing and coping with stress, and the wearable (the mentor) can learn more about that person's learning styles, and habits and preferences in dealing with stress. The identification of this genre is mostly based on participants' reflections on—and speculations about—the long-term use of smart wearables, and less on what the design enactments could express directly.

The physical form of smart wearables as mentors can be characterised as being *sentient* because they have the wisdom and sensitivity on the topic of mentoring. For example, one of the participants mentioned how the stroking movement of the robe on the person's back should provide a kind of sensitive and emotional support. Although a person was controlling the balls' movement, it indicates how computational things might express a similar sensitivity to that of humans or other living beings. At this point, the participants who created the vest thought about how smart wearables should learn from a person's posture and movements to make the interaction more natural and comfortable. Of course, it is a matter of debate whether or not such adaptive and learning behaviour make the wearable a mentor or "just" an adaptive collaborator. To give an example of an aspect of mentoring behaviour requiring a specific physical aspect, is the notion of discussing with the wearer about the mentoring goals. That kind of discussion requires a means for the verbal (spoken or text-based) interactions with the wearer, which, for example, in Grippy (a smart wearable system to encourage people to seek out and learn to cope with stress; see Chapters 5 and 6) led to the addition of an app on the mobile phone that accompanies the physical glove of Grippy. Thus, the physical aspects of the Grippy system are both the glove and the app on the smartphone. An interesting discussion point is how these perceptions of smart wearables can be established.

In terms of temporal form, smart wearables as mentors *mature* over time. Unlike smart wearables as organs that only respond to sensed bodily changes or as collaborators that follow predefined procedures, smart wearables as mentors are more flexible by learning from the historical experiences with the wearers. Their behaviour thus may become more appropriate over time, or even "wise"—when considering wisdom to be an outcome of learning by experience (Alloui et al., 2015; Özcan, 2015; Schifferstein et al., 2015). An interesting question here is how the maturing behaviour of smart wearables can be perceived as an expression of the growing 'wisdom' of a singular entity rather than being perceived as a collection of changeable behavioural patterns.

The interaction with smart wearables as mentors is considered *co-developmental*, as both the smart wearable and the wearer learn from each other over time. The smart wearable can vary its behaviour based on sensed data and the person's feedback to the intervention, and, through this adaptive process, help the person to reflect on his or her stress experiences and gain new knowledge or skills. At this point, the students who designed the vest argued that it should help the wearer to gain confidence and face the problem. An emerging design question is what the smart wearable can *become* and if the smart wearable makes itself *obsolete* when a particular kind of competence has been internalised. An interesting reflection on this question can be found in Frauenberger (2020) who discusses a speculative future in which smart things evolve and engage us in "a constant state of agonistic negotiation about what we want them and us to be" (p. 89).

3.5 Discussion

This vocabulary presented above helps us to identify different kinds of partnerships that smart wearables could embody by means of their expressive features across their physical form, temporal form, and interaction gestalt. Briefly speaking, we argue that smart wearables can be described as organs in terms of meaningful *translations* of sensed signals into actuations, *ephemeral* reactions to sensed signals and how they could trigger *reflexive* actions of the wearers. To understand smart wearables as collaborators, we suggest that such smart wearables should be able to express their *intention* explicitly, to engage the wearers in continuous dialogues across different phases of a *procedure*, and to remain open for *negotiation* with the wearers to decide upon whether to follow or take the lead. Lastly, we propose that smart wearables as mentors can *matur*e over time and embody a more intelligent kind of partnership in which the smart wearable and the wearer are equal and can learn from each other over time (*co-development*). The vocabulary of mentors also emphasise the importance of computational complexity that allows the wearable to show varying changing behavioural responses, and how this might raise the need to express an artificial kind of *sentience* through its material manifestation.

We would also like to elaborate on how these genres are conceptually distinct from each other and can coexist in the interaction given the complexity of the interaction with smart wearables. First, the distinctions of these genres in physical forms are reflected in how they translate sensed signals to the wearers. Organs *translate* the sensed signals into actuations that trigger awareness and intuitive actions which require little attention of the wearers, like the driving shoe which directs the driver's attention to his foot on the gas paddle. Collaborators use the collected information as an input to inform an *intention* to invite or inhibit certain actions of the wearers. For example, the headphones choose to calm the person down, by means of smoothing music and massage-like vibrations, or *force* the person to take a break depending on the levels of stress that has been sensed. Information collected by the mentors can be taken as a piece of memory that informs a long-term learning and growth as *sentient* beings, like the vest that could learn from the wearer's posture and movements to make the actuations more natural and comfortable after wearing for a while.

Second, these genres differ from each other in how their behavioural patterns are aligned over the timespan. The organs act *ephemerally* as a direct and spontaneous response to sensed signals or actions of the wearers, similar to the human body that can reflexively respond to external stimuli. The collaborators' behaviour are framed as a predefined sequence of actions that exist in an episodic manner. We can imagine that the algorithms of the vest can be structured as a series of "if-then-else" statements which make the vest always behave the same way in response to the sensed signals and could expire when a predefined time has passed. The mentors can adapt their behaviour according to learning from the interaction with the wearer over time. Taking the same example of the vest, the strength and rhythm of its action of encouraging one to move shoulders could adapt to one's habitual behaviour or preferences as long as the person is wearing it. By doing so, the vest could become more attuned to the wearers. In terms of our vocabulary we interpret this as, the vest, being designed as a mentor, would be able to change its procedure of interactions (learning on the job), which is a form of maturing (temporal form of mentors).

Third, in terms of the interaction gestalt, the three genres can be distinguished by the manner in which they invite or inhibit actions of the wearers. The organs involve the person in the interaction by *triggering* one's reflexive behaviour without having full attention of the person, for example stretching shoulders when feeling pressure on the shoulders (the vest) and pulling back the foot as a response to the sting at the bottom of the foot (the driving shoe). The collaborators approach the wearer in an *inviting* or *inhibiting* manner by advising or hindering certain actions that the person could take. We interpret the interaction with the mentors, in terms of our vocabulary, to be a co-developing process for both parties of the partnership. Both the wearables and the wearers are not isolated units with fixed behavioural patterns, but can learn from and adapt to each other over time. Imagining the sleeping robe as a mentor, the way in which the robe comforts the person might change when the baby grows up and the mother does not need to attend to the baby as often as it used to be.

The three genres can coexist depending on perception of the individual and the interaction over time. For example, our experiences in the workshop show how the concept of the vest could be described to function as an organ to help the wearer become aware of stress, as a collaborator to guide the wearer through a relaxation exercise, and as a mentor to help build the wearer's confidence over time. We can speculate that a computationally complex wearable that is designed as a *mentor* to learn about a person's stress situations and coping behaviour *over time* might be experienced as a *collaborator* when it guides the person through a particular stress-reducing exercise. Due to learning, that same wearable might be experienced as an *organ* when the person learns to internalise the exercise and becomes less aware of the interaction with the wearable. As a wearable learns better about the wearer (as a *mentor*), it might also be able to adjust the manner in which it could approach the wearer, i.e. a mentor could decide to behave as an organ or a collaborator depending on its understanding of the person and the current situation. Given these variations in the experience of smart wearables across the three genres, it would be interesting to further investigate how smart wearables can be designed to allow these experiences to vary over time.

3.5.1 Reflection on the genres from a postphenomenological perspective

From a postphenomenological perspective, technology mediates our relationship with the world. Idhe (1990) suggested four different human-technology relations, i.e., *embodiment*, *hermeneutic*, *alterity* and *background* relations, see Table 3.2. Embodiment and hermeneutic human-technology relations help us 'directly' perceive and act within the world or disclose aspects of it by 'reading' it, respectively. We interpret our work in relation to these human-technology relations as follows. Partnering up with smart wearables as 'organs' can relate to both of these human-technology relations. As 'organs' smart wearables function as an additional artificial organ to sense stress, augmenting the human body through technology. Experiencing such organs as external devices that need to be read when worn makes the human-technology relation a hermeneutic one. If the organ becomes incorporated into the bodily experience of sensing stress (without an experienced distinction between the device and body), an embodiment relation is established. Idhe further proposes how alterity relations frame technology as quasi-others, something external to you. Partnering up with smart wearables as collaborators and mentors suggest such an alterity relation. For both genres smart wearables have intent and can act separately from the wearer. Idhe describes background relations as technology that becomes the backdrop of human experience (i.e., technology that is part of the context). Background relations are relevant for discussing smart wearables as partners because they are worn. Clothing has an interesting quality of being "present and absent at the same time". This notion of the technology being present and absent at the same time is introduced by Verbeek (2005, p. 128). The genres address this background relation implicitly. Whether smart wearables are characterised as organs, mentors or collaborators, they act from their position of being co-present in the situation as a piece of clothing or accessory. This assumes that wearable partners are required to remain comfortably 'in the background' when they are not actively used.

Table 3.2. Definitions of the four basic human-technology relations. These definitions are taken from Rosenberger and Verbeek's (2015, pp. 13-19) review on Ihde's (1990) work.

	Embodiment Relations	Hermeneutic Relations	Alterity Relations	Background Relations
Explanations of the technological mediation	Technologies that transform a user's actional and perceptual engagement with the world	Technologies that are used through an act of perceiving and interpreting the device's readout	Technologies to which we relate in a manner somewhat similar to how we interact with other human beings	Technologies that make up the user's environmental context

Postphenomenological studies of wearable technologies that focus on the characteristics of the wearable in mediating relations between human wearers and the world, are, for example Toussaint (2018) and Van Dongen (2019). Toussaint (2018, p. 92) emphasises the consideration of the cultural status of wearable technologies and argues that wearable technologies affect the way people perceive the world and "are perceived by the world", and also their self-perception. For example, how one perceives the contours of his or her body by wearing a skin-tight garment. Van Dongen (2019) proposes a *material-aesthetics framework* inspired by postphenomenology to look into how wearables (garments) shape our perception and interpretation of the world, as well as our behaviours within it. She illustrates how such a framework could equip designers of wearables with a material understanding that goes beyond functionality. Our vocabulary, informed by Vallgårda's (2014) framework on formgiving practises in interaction design, shares a common ground with the phenomenological studies of Toussaint (2018) and van Dongen (2019) on the level of materiality and experience. In particular, these ideas all consider that material properties of cultural artefacts have consequences for their experience and use. Thus, the smart wearable genres of organ, collaborator and mentor have distinct properties that cause them to be experienced and interacted with differently.

3.5.2 Contribution and relations to other fields

In this section, we discuss how this vocabulary contributes to developing work on intelligent agents and persuasive technology for mental health. We also reflect on how our work relates to somaesthetic design and can be taken up by designers.

Artificial intelligence and Human-agent interaction

Artificial Intelligence and Intelligent Agent technology, and in particular the efforts on the architectures for creating artificial intelligence within an agent, typically has a view on agents that are separate entities from the human user. The same holds for the typical view on human-agent interaction (and certainly for human-robot interaction). The notion of a smart wearable as either organ, collaborator and/or mentor might be intriguing for these researchers. The fact that the smart wearable is literally on our bodies, challenges the way of thinking about the agent's intelligence as separate from that of the human user. We hope that this prompts an outside-in perspective that can help to properly design the required intelligence of smart wearables. By this we mean a relational way of thinking about the body, intelligence and interaction as is done in the Embodied Embedded Cognition literature on agents (Dauthenhahn et al., 2002), and in augmented intelligence (Zheng et al., 2017). In this sense the idea of the genres of smart wearables as organs, collaborators and mentors could form a bridge between the communities of agent technology, augmented intelligence, and embodied embedded cognition. Furthermore, these genres of smart wearables could become a real inspiration for the upcoming notion of Hybrid Intelligence, i.e., the intelligence that combines artificial intelligence with human intelligence, instead of trying to copy or replace human intelligence (see Akata et al., 2020).

To explain this in more detail, we connect the genres with some of the work that categorises levels of intelligence for the benefit of agent technology and not with the main stream of work on beliefs, desires and intentions (BDI-inspired architectures, see e.g., the seminal work of Rao and Georgeff, 1995). The BDI architectures already tune in on a more complex type of intelligence than needed to generate the intelligence of an organ. For that reason, we chose to compare our work to that of Jonker and Treur's (1998) who focus on the requirements of internal structures of the brains of agents in relation to the kinds of behaviour these enable. Jonker and Treur (1998) identify four types of agent behaviour, i.e., *purely reactive behaviour*, *delayed response behaviour*, *proactive behaviour*, and *social behaviour*, by reflecting on animals' behaviour and how these behaviours can be simulated by computational agents. According to them, *purely reactive behaviour* represents the reflexive behaviour of animals that are intuitive responses to the stimuli, which can be simulated by the condition-action rule of algorithms: "if condition, then action". The *delayed response behaviour* of animals suggests they might have memory of something that has occured before and could relate it to the current situation. For example, a dog might search in places where it has found food before. To simulate this behaviour, a computational agent has to contain an internal structure that allows for it to observe and retrieve relevant memory that matches the current situation. *Deliberate proactive behaviour* is not directly related to stimuli, neither immediately, nor delayed; it represents its own motivation or goal (like the desire to eat). *Proactive behaviour* can be simulated by making the computational agent able to determine one or more goals and evaluate the status of whether the goal has been achieved so as to inform the proper actions to take. The *social behaviour* of animals can be observed when they communicate with other agents. For example, an animal might give up the intent to get the food when it senses the intimidation of another animal who is more dominant in the situation. A computational agent with social behaviour has to be able to identify new communicated knowledge about the other agents.

Organs can be understood as the kind of (wearable) agents that present *purely reactive behaviour*. To make use of this behaviour in the interaction, designers should think about how agents could 'translate' the sensed signals properly, whether they are 'ephemeral' so that users could intuitively relate to the current situation, and smoothly connected to 'reflexive' behaviour of the wearers. Collaborators can behave as both *proactive* and *social agents*, which have their own goals and are able to communicate with the human wearers. For such agents to be sufficiently understood by the users, attention should be paid to whether their 'intentions' are explicitly expressed, how they could behave differently in different stages of the activity ('procedural'), and how to reach agreement with users through 'negotiation'. As for mentors, typical *delayed response*, *proactive* and *social behaviour* could be recognized when they adapt to the wearer's needs and preferences and fit with the social situation. To make sure these agents are appropriate partners in the interaction, design effort can be made to shape them *as if* 'sentient' beings, and present new behaviour by learning from the person and the situation ('maturing' and 'co-development'). For scientists in agent technology this work indicates that more intelligence is not always useful. For example, augmenting humans with an additional artificial organ requiring only a purely reactive type of intelligence might be what provides the wearer with the experience and support needed. In short, for smart wearables the level of intelligence should fit with the purposes of organs, collaborators and mentors.

Persuasive technologies for mental health

The genres we propose also relate to research on the application of persuasive technologies for mental health, in particular for stress-related conditions. Persuasive technology as a field of science aims to change people's attitudes or behaviour by means of different strategies and the use of technology (Fogg, 2002; Lockton et al., 2008). The link to the previous fields of research is as follows: for persuasive technology it is important to design intelligent persuasive agents that support people to change their behaviour via social feedback and affective behaviour (Khan & Sutcliffe, 2014; Midden & Ham, 2008). Applying persuasive technology for stress management, is a challenge by itself, as research by Maclean et al. (2013) shows that making users be aware of their stress might instead lead to increased stress. The design of persuasive technologies for mental health requires a multidimensional understanding of *what* and *how* the persuasive behaviour of *intelligent agents* should be shaped to benefit the users the most.

Our genres provide insights in this direction as our genres can be aligned with existing work in persuasive technology for mental health behaviour change. Wearables as organs refer to technologies that provide peripheral information to enhance people's awareness of stress, as shown by biofeedback-devices (see Peake et al., 2018 for an overview of these applications) and still leave freedom for a person to decide whether and how to attend to his or her stress (e.g., Sanches et al., 2010). The genre of organs also align with the underlying principles of nudging technology (see e.g., Sunstein, 2015) in that they require little attention from the users, hardly interfere with the users, while still triggering them to adopt new behaviours. Smart wearables as collaborators can provide behavioural kinds of support by assisting a person to achieve specific therapeutic outcomes by doing exercises (see Burger et al., 2020 for an overview of the persuasive technologies with a therapeutic approach to address diagnostic mental illness). Therefore, the wearable collaborators should be smart enough to negotiate with the users to reach an agreement on how and when to interact in ways that fit with the person's capability and the situations, and provide guidance across the process of the activities. Lastly, smart wearables as mentors may serve as e-therapists that build up knowledge of a person over time based on continuous monitoring, and which can initiate training-strategies and provide tailored advice. Relevant work can be found in which intelligent agents are shaped as virtual therapists (Tielman et al., 2017). Whether and how such a role can be embodied in wearable technologies requires further work.

Somaesthetic design

Our work also is related to the research on somaesthetics in HCI, where bodily experiences are explicitly explored as a design resource (Shusterman, 2008). Höök et al. (2016) proposed the notion of "somaesthetic appreciation" to encourage designers to gain sensitivity about the embodied and sensorial aspects of a design in the early stages of the design process. The methodology of our workshop follows this principle. We invited participants to connect with their body to explore sensations, feelings and movements, and to make use of these experiences to inform and inspire their design concepts. This helped them to design *with* the body rather than *for* the body and we noticed how this provided a broader and more nuanced understanding of their own experience. For instance, one student mentioned how the workshop helped her discover and make use of the habitual behaviour that she would normally overlook. We further noted how the participants learned to understand body movements as being an expression of stress as well as a means to manage it. This also links to the research (Gallagher, 2006; Pfeifer & Bongard,

2006) that state that body movement such as postures and gestures are recognized as indicative signals of people's emotions, and bodily movement could, in turn, influence our emotions, states of mind, and even cognitive processes.

How the genres can be taken up by designers

Design vocabulary is a form of knowledge for designers to understand the complex phenomena brought about by the use of new technologies, and vice versa to make use of new technologies to satisfy individual and societal needs. For example, both Diefenbach et al. (2013) and Chuang et al. (2018) propose design vocabularies to describe interactions with products and interactive systems with the aim to inspire and support communication within design teams. Similarly, our vocabulary could be taken up as an 'inspirational tool' to stimulate creative thinking during a design project of a smart wearable so that it will function as a partner for its user as an organ, collaborator and/or mentor. By determining which one or more genres to achieve, designers could use the corresponding vocabulary to sketch out possible appearances and behaviours of wearables. For example, to design an organ-like wearable, a designer might start with thinking about translational actuations that could stimulate the wearer's natural body movements as part of the reflexive interaction. Second, the vocabulary could be used 'as a set of reminders' to help designers keep track of the intended experiential qualities when crafting the technologies. For example, in the vocabulary of collaborators it is essential to leave room for negotiation between the wearables and wearers. With this in mind, designers should be more sensitive to the manners in which the wearable engages the person in a collaborative activity to allow for the person to make his or her own decisions. Third, the vocabulary could be developed into a 'checklist' to evaluate the use experiences of wearables of a particular genre. For instance, a wearable designed as an organ could be evaluated by looking at how intuitively the person is able to pick up the translated signals (actuations) without previous instructions. Finally, the vocabulary could be used as a 'communicative language' within the design team. The genres, together with their vocabulary, could be useful to open up and steer the conversation between team members along the process of a design project. For example, the vocabulary can be used between designers and engineers to reach a shared understanding of what a mentor-like wearable could behave in a maturing manner, and how it could co-develop with the wearer over time of wearing.

3.5.3 Limitations

We identify three factors that limit the generalisation of the findings. The first is concerned with relying on *novice design students* as participants. Given the fact that the students were novices in design, used to support articulation of the vocabulary, we realise that the genres might need further refinement when used in different contexts or applied to different design projects. The second is concerned with the workshop method. Although we asked students to detail the appearances and mimic the behaviours of their design as well as possible, their manifestations are limited by the available tinkering materials and the participants' puppeteering skills. Furthermore, we did not prepare specific applications, but allowed the participants to come up with their own ideas. As we asked them to focus on bodily experience and not on the realism of the application, 'naive' design concepts were produced with respect to, for example, contextualisation, effectiveness, and their social impacts. For example, although we elaborate on the negotiation between the vest and the wearer, it remains a question whether people could understand the wearable device and behave as we envisioned in the workshop. The anticipation about the use experiences of their designs was based on their own life experiences rather than target users (by doing research based on their real problems and use situations), which makes these anticipations inherently biased. The third is concerned with the *technical feasibility* of the design concepts. The designs can be said to show a lack of technological detail and prone to rely on unfounded assumptions about what technology is capable of. For example, some of the designs by the students assume that stress can be detected accurately in real time. In general, this remains a technical challenge despite the rapid developments in this field (Garcia-Ceja et al., 2018).

3.6 Conclusion

In this chapter we propose a vocabulary to guide the formgiving practice of designing smart wearables as partners. We argue that our work contributes to, not only the research field of design, but also to the fields of AI and agent technology and, more specifically, to the design of persuasive technology for mental health. Finally, we related our work to somaesthetic design. As a contribution to the research field of design, we identified three genres of smart wearables as partners: *organs*, *collaborators*, and/or *mentors*. Their distinctness is elaborated in terms of how they are *expressed* through their physical form, temporal form and interaction gestalt. We discuss how they can coexist in one smart wearable and can adapt over time by the interaction of the smart wearable with the wearer. The chapter aligns the vocabulary of the three genres with postphenomenological theories and frameworks about wearables and the relationships they establish with their users. For the fields of artificial intelligence and agent technology the idea of conceiving smart wearables as agents, and the genres by themselves are noteworthy. In particular, we show how thinking about the use and experience of smart wearables provides an outside-in perspective on agents that gives purpose to their internal structure that can generate the required level of intelligence. In a sense, our work makes it more tangible, that the level of intelligence should fit the purpose of its use. This is an intentional pun on the typical focus of researchers in agent technology on the mental capacities of the agents, neglecting the fact that the agent, through its embodiment, is directly connected to the body and mind of its wearer. We argue that our work strengthens connections between the research fields of Artificial Intelligence and that of Augmented Intelligence and Hybrid Intelligence. For the research field of persuasive technology for mental health, we show how the three genres also provide some insights on how to design smart wearables with multiple strategies for persuading the wearer to change his behaviour that correspond to the genres of organ (nudging), collaborator (training, and awareness) and/or mentor (reflection, learning, and tailored strategies).

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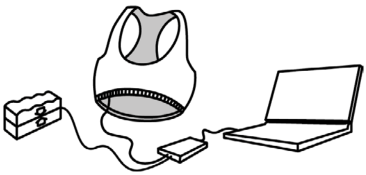
CHAPTER 4

Prototyping an Integrated Wearable System for Biosensing and Self-reporting of Stress



This chapter is based on Xinjie Zhang's Master graduation project (Zhang, 2018) conducted at Delft University of Technology, which is planned and conducted under the scheme of this PhD project. It has been published in:

Li, X., Jansen, K. M. B., Zhang, X., Rozendaal, M. C., & Jonker, C. M. (2020). Designing an Integrated Wearable System for Biosensing and Self-reporting of Stress. In *The 6th European Conference on Design4Health* (pp. 116-125).

Changes have been made to better align this chapter with the overall reflections presented in Chapter 7.

This chapter describes the process of making and testing a prototype of a wearable system that is able to collect physiological data about stress and enables the wearer to report on it. By integrating physiological sensors in a garment and testing its performance in the lab, we learned about the complexity to obtain good-quality data using such sensors and how participants experienced wearing it. Furthermore, we report on the design and use of a squeezing bar as a tangible interface to self-report on stress. The prototype was evaluated by 11 participants who wore it while going through a stress inducement experiment in the lab. Insights and techniques learned from this chapter were used in the making of a smart glove, as presented in Chapter 5.

4.1 Introduction

The conceptual framework on smart wearables as partners that we proposed in Chapter 2 brings technical challenges concerning their realisation. One of the key aspects the framework describes is how wearable partners should get an 'understanding' of the level of stress a person experiences by combining and aggregating multiple data sources. In this study, we specifically study the technical challenge of measuring stress based on biomarkers (physiological data) and by means of self-reporting on it (subjective data).

The challenge of sensing physiological data with wearables is how to capture good-quality data with wearables that are also comfortable to wear. A variety of wearable technologies have been used to sense stress in everyday contexts based on physiological signals, such as heart rate, electrodermal activity, and respiration (Choi et al., 2012). An often-described problem includes the accuracy of wearable sensors and disturbance caused by the body movements (Vanitha et al., 2017; Aqajari et al., 2020; Choi et al., 2012). Another problem concerns how to integrate sensors in garments without compromising their wearability. Therefore textiles are researched and developed that integrate electronics in fabrics by, for instance, conductive threads and ink (Castano et al., 2014; Karim et al., 2017) and flexible printed circuit boards (PCBs) (Petropoulos et al., 2012).

The challenge of sensing subjective data with wearables is how to allow people to self-report on stress in a way that is intuitive and which does not distract too much from what one is doing at that moment. Various self-reporting methods have been developed to help people register their subjective stress. Examples include Studentlife (Wang et al., 2014) and Mood Monitor (Nadal et al., 2021) which are smartphone apps that can enable users to log their moods by means of digital labels and scales. However, such applications require continuous effort of the users to consciously check and report their stress and therefore might be experienced to disrupt the flow of daily activities (Kusserow et al., 2012; Adams, et al., 2014). Furthermore, devices with small-sized touch-screens and physical buttons like wristbands (e.g., Fitbit) or smartwatches (e.g., Apple Watch) can make self-reporting methods cumbersome to use.

An interesting development here is the use of tangible interaction as means of registering or expressing emotions which can provide a means of self-reporting. For instance, Jingar and Lindgren (2019) employed a co-design approach to invite people to create tangible prototypes of intelligent agents as digital companions. They learned how the touch and feel of these prototypes was a key determinant that allowed people to fidget or play around with them. These actions provide people a way to relieve their stress and can be read by the agent as emotional expressions. The Grasp platform by Guribye et al. (2016) provides an example of a self-reporting tool that uses squeezing an object—resembling a stone that can be easily held in the palm of the hand—as a means to capture a representation of one's emotional state as it occurs with a degree of control over the registration. Both these works highlight the potential of using tangible interaction as an alternative means for self-reporting on stress.

In this study, both kinds of challenges are explored. We describe the process of developing a prototype of a wearable system that measures stress by reporting on the selection of physiological sensors, their integration in a garment and the development of a self-reporting tool based on squeezing. We report on a stress inducement experiment with a garment in which physiological sensors are embedded and a self-reporting tool (in the form of a squeezing bar). In the experiment the garment and the self-reporting tool were evaluated regarding their ability to sense stress in the lab. We also report on how participants experienced wearing and using the prototype.

4.2 Design

4.2.1 Selection of physiological sensors

In the design of the garment, we chose three sensors aiming for the biomarkers of heart rate (PPG heart pulse sensor), electrical conductance of the skin (Grove GSR sensor) and skin temperature (Thermistor–3950 NTC). The biomarkers of heart rate and skin conductivity are commonly used for measuring physiological stress (Choi et al., 2012) and the sensors are easily available off the shelf and relatively cheap. The changes of body skin temperature also provide clues on the stress induced by the stressors depending on the site of the measurement on the body (Vinkers et al., 2013). In addition, we chose a data acquisition device (DAQ 6009) to log the captured data and used desktop software (LabVIEW) to analyse it (Figure 4.1). Note that the decision was made to work with an Arduino-based sensors system, because commercially available wearable devices with sensors and computation embedded in them (e.g., Fitbit and Apple Watch) are technically blackboxed and difficult to work with in new configurations, although they have increased performance/accuracy.

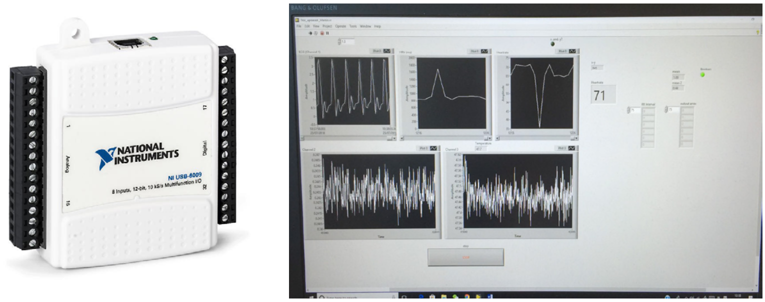


Figure 4.1. The device for data acquisition (DAQ 6009; left) and the interface of data processing software (LabVIEW; right).

4.2.2 Integration of sensors in a garment

A women's gym top made of a light and stretchy textile was used as a garment to experiment on. A gym top was chosen because it allowed the sensors to become easily positioned at the right locations on the body where the sensors could make contact with the skin directly. As shown in Figure 4.2, all three sensors were located on the left side of the chest to minimise the effects caused by limb movements. To protect the connection of the sensors, we covered the sensors and wires in between two layers of fabrics and only exposed the sensor heads that require contact with the skin. The garment (with sensors embedded), the self-reporting tool (as introduced below) and the data acquisition device and algorithms made the prototype of the wearable system.

Figure 4.2. Connection of electronics (left) and placement of sensors in the garment (right). Design and photo by Xinjie Zhang.

4.2.3 Developing a self-reporting tool

In addition to the physiological sensors integrated in the garment, we created a self-reporting tool which could be used to correlate experienced stress with the signals measured by the garment. We chose the gesture of squeezing fingers in the hand palm, or making a fist, because it is considered to be a natural way of expressing stress (Lefter et al., 2015; Neff et al., 2010). This principle has been used in the development of tangible user interfaces that register one's affective status (e.g., Guribye et al., 2016). We developed *a squeezing bar* (Figure 4.3) which is made of a standard force sensor (Grove–FSR402) and two pieces of foam. The sensor is connected to the computer through an Arduino board. The user can report on experienced stress by adjusting the strength applied to the foam when squeezing it: the harder the user squeezes it, the higher level of stress is reported.

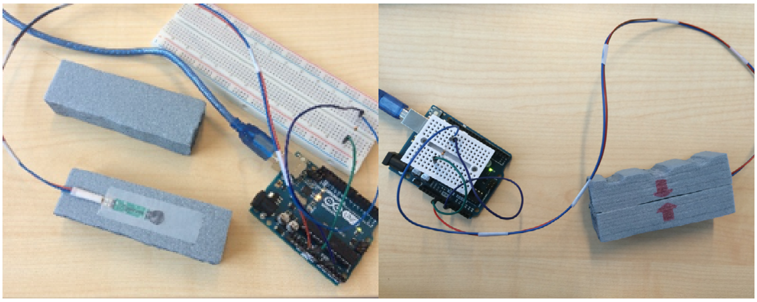


Figure 4.3. The self-reporting tool (the squeezing bar) of Prototype 1. Design and photo by Xinjie Zhang.

4.3 Evaluation

4.3.1 Participants and procedure

This prototype was introduced to 11 male university students (aged between 24 to 30) who wore it on their skin, underneath their own clothes, while being exposed to three stressors in a stress inducement experiment. The participants were recruited through the personal network of the experimenter (Xinjie Zhang). Only male participants were recruited because the placement of the heart rate sensor would make it uncomfortable for women to wear, and thus to participate. The experiment was conducted in a quiet room. Participants were asked to put on the garment in advance and sit in front of a computer with a pair of headphones on. The experimenter sat beside the participant and observed the data generated on another computer connected to the prototype. Figure 4.4 shows an impression of the experiment. The experiment lasted for about one hour, including an introductory session (5 minutes), exposure to the stressors (5 minutes for each), intermediate break (5 minutes after each stressor), and a debriefing session (20 minutes).

The chosen three stressors were adapted from the stressors that have been used by other researchers to induce stress in laboratory settings (Choi et al., 2012; Plarre et al., 2011; Müller et al., 2016). The study has been approved by the ethics committee of Delft University of Technology and an informed consent form was signed by each participant before the experiment.

The experiment was set up as follows. The three stressors (that will be explained in the next paragraph) were arranged in chronological order with a 5-minute break in between. Figure 4.5 shows the timeline of the experiment. Before the experiment, a video was played showing natural scenery with soothing music to help the participant relax, hereby creating a baseline stress level. This video was also shown during each break to help the person recover from the previous stressor. In the debriefing session, the participant was asked to rate the three stressors on a 6-point Likert scale (ranging from 0 to 5). This way, participants could retrospectively report on the levels of stress experienced for each video. Three questions were then asked to learn about how the participant experienced wearing the garment and using the self-reporting tool. These questions included (a) how they experienced the three stressors? (b) what they thought about the wearability of the garment and the usability of the self-reporting tool? and (c) how they would envision the use of such a system in their daily life? The raw data collected from this experiment can be accessed through an online repository system[2].

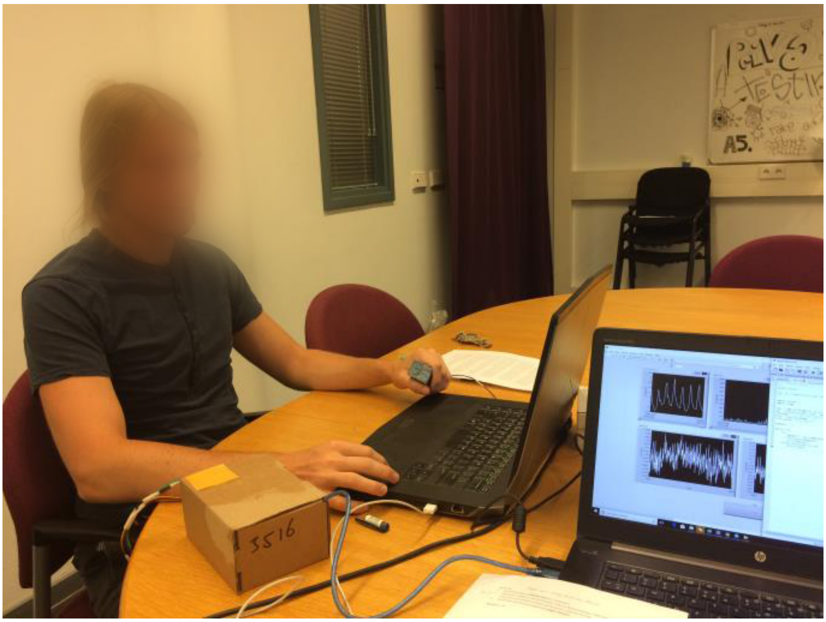


Figure 4.4. Impression of the experiment to test the garment and the self-reporting tool. Photo by Xinjie Zhang.

[2]The raw data collected from this experiment, including self-reported data generated by the force sensor, the scores of the Likert scale and transcription of the debriefing interview, can be accessed through this link: https://surfdrive.surf.nl/files/index.php/s/42Ok1tRtMLeKfap

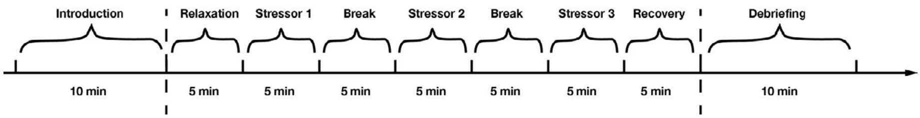


Figure 4.5. Timeline of the experiment.

4.3.2 Stressor manipulation

We refer to the work done by Choi et al. (2012), Plarre et al. (2011) and Müller et al., (2016) on stress inducement techniques. Choi et al. (2012) describe techniques that rely on stress induced by performing complex perceptual motor tasks such as tracking a moving target on the screen using a mouse and manually tracing a pattern on a paper through a mirror. Plarre et al. (2011) describes techniques that rely on social or sensorial means to induce stress. For instance, by asking a person to give a speech in front of the camera or by inserting one's hand in ice-cold water. Both have described stress inducement techniques that rely on cognitive effort, such as doing complex mental arithmetic or by memorising words under time pressure. Müller et al., (2016) describe the use of jump scare events to trigger stress using a 3D game scenario "where monsters spawn in front of the bike [the player controls] shouting a horrible sound and all player controls are disabled" (p. 4). We have created three stressors intended to elicit *low*, *intermediate* and *high* levels of stress by combining some of these techniques.

Stressor 1: Fast reading

For this stressor, each participant was asked to read a complicated article in 5 minutes about PTSD. Meanwhile, a piece of intensive music was played through the headphones that increased in volume over time. After this, questions were asked about some details of the article while telling the participant that his answers would be recorded and evaluated by the researcher afterwards. This setup is intended to elicit mild levels of stress by means of adding sound stimulation to a relatively easy reading task and by adding some social pressure during the question round.

Stressor 2: Mental arithmetic

Each participant was asked to continuously add up three-digit numbers without the use of any external support such as the use of the fingers, pen and paper or calculator within five minutes. This stressor is adapted from the "mental arithmetic" technique by Plarre et al. (2011). To make this task more demanding, we added the sound of a ticking clock to emphasise the task's time constraint that created a sensory distraction at the same time. Compared to Stressor 1, this stressor is more demanding as the number of summations would be too high for most people to finish in 5 minutes, which is intended to induce medium stress.

Stressor 3: Sudden appearance of a scary image

Each participant was asked to look at a video clip that showed the screen capture of a video game in which a cartoon-like character jumps over different types of barriers while collecting stars on the screen. The video clip ends with an image taken from a scary movie that shows the sudden appearance of a ghost-like character. Although participants were briefed that there would be a scary moment while watching the video, participants were left in the dark about what this is about and when it would be happening. This setup is intended to elicit high levels of stress caused by a *jump scare* event that has been found to trigger an immediate arousal response (Müller et al., 2016).

4.3.3 Results

An initial examination of the physiological data was conducted to find out their correlations to the occurrence of the stressors and participants' experienced stress. The raw data of the heart rate (beats per minute, BPM) contained much noise and was not directly useful for the correlation for the algorithm that is part of the software delivered with the sensor. Maybe more advanced algorithms could make better sense of it, for example, by analysing the Heart Rate Variability (HRV). HRV refers to the variation in the beat-to-beat interval and might give more information on how the continuum of the heartbeats is influenced by the external stimuli. However, the noise in the data would also hamper that analysis. As for skin conductivity, the recorded data of five participants' showed little changes across experimental conditions, suggesting a poor sensor-to-skin contact despite our efforts to integrate this sensor in the garment to safeguard it. For the other six participants, large sudden jumps were observed in the measured conductivity values. This can be attributed to changes in body movement as participants adjusted their sitting postures during the experiment. Lastly, the skin temperature of all the participants showed mild uptrends but showed no clear correlation to the occurrence of the stressors either. In short, the findings above have revealed the difficulty of obtaining good-quality physiological data due to poor sensor-to-skin contact and interferences caused by body movements. Because of this, we could not draw any conclusion about the person's experienced stress related to the measured physiological data.

The subjective stress data collected from the self-reporting tool showed relatively more information on how and when the person felt stressed, see Figure 4.6. For some participants, the scores on the Likert scales correspond to the self-reported data based on the force of squeezing the bar, see A1, A2, A4, A6, and A11. For example, the self-reported data of A1 shows that Stressor 3 induced the highest level of stress, Stressor 1 intermediate levels, and Stressor 2 the lowest levels of stress, which was consistent with the way he rated the stressors on the Likert scale afterwards. However, for some participants the Likert scale scores did not match the squeezing, e.g., A3 reported Stressor 2 as the most stressful while in the Likert scale he rated Stressor 3 as the most stressful one. The self-reported data (sensed force of squeezing) could also be used to indicate the time when a stressor occurs. It could also be imagined that this data might be used to filter out false signals in the physiological data and train the algorithms to be able to recognize stressful moments more accurately.

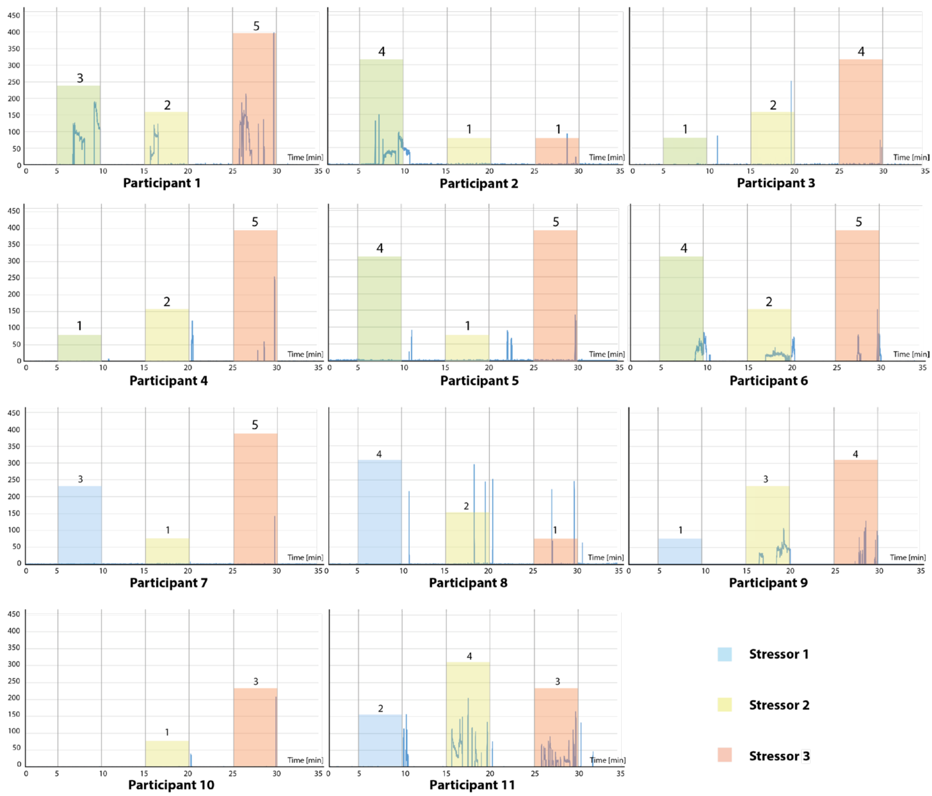


Figure 4.6. Comparison of participants' self-reported data (sensed force of squeezing) and stress scores on the Likert scale. The x-axis is the time (min). The y-axis is the sensed force of squeezing (N). The scores of the Likert scale of the stressors are placed on top of the colored columns.

From the debriefing interview, we learned about how the participants experienced wearing the garment and interacting with the self-reporting tool. Although the garment was made of stretchy fabrics, it was found too tight for some participants (A1, A2, A4, A8, A9 and A10). A10 mentioned that the wearability of the garment could be improved by making it *adjustable*. One participant (A5) mentioned that the appearance was too feminine to him, a thing which would refrain him from wearing it. As for the self-reporting tool, mixed feedback was received about its use. Some participants appreciated the use of it as a natural and intuitive way to report immediate stress, like A5 who said that “this tool reminds me [the feeling] of holding somebody’s arm to get support.” A6 mentioned that it “might be a good way of getting results regarding how much stress you feel [at the moment].” A9 said the self-reporting interface was “comfortable to hold” and he could squeeze “subconsciously”. Similarly, A10 referred to the action of squeezing as “a kind of normal reaction” when he was under stress, but he added that this was also “something you have to get used to” before “it will become a habit.”

Limitations in the design of the self-reporting interface were also found. For example, four participants (A1, A2, A3 and A7) said that they needed *immediate feedback* so that they would know how much force they were applying to the palm, and thus the level of stress they were reporting. In addition, A3 reported that interaction with the squeezing bar would *disturb* the activities we asked him to carry out during Stressor 1 and 2. Furthermore, three participants (A1, A6 and A8) mentioned that interaction with the self-reporting tool could lead to *paying extra attention* to stress, which could become another source of stress. To improve the design in this respect, some participants (A1, A6, A8 and A11) would like to see some *progress* in coping with stress, instead of only being told that they were stressed. As said by A1 about the self-reporting tool in relation to the garment, “if I can be informed that my stress condition is getting better, I will feel positive and more willing to wear it.” A7 suggested combining self-reporting with specific *relaxation activities*, such as meditation. Finally, as suggested by A1, the form of the self-reporting tool should be more socially appropriate and better integrated with the garment since people might not be able to hold this tool all the time during the day.

4.4 Discussion

Overall, the way we integrated sensors in a garment to measure biomarkers of stress turned out to be difficult to provide direct indication to the occurrence of stressors, not to mention specific levels of stress perceived by the users. As have been learned from the user test of the prototype, the physiological data was difficult to interpret due to bad sensor-to-skin contact and body movements. The self-reporting interface was found to be more useful. Compared to the physiological sensors, collecting self-reported data using the self-reporting tool seems to be useful to help describe when and how the person is stressed. In addition, such self-reported data can be used to finetune the physiological data and train the algorithms to better recognize a person’s stress status.

Insights were also gained about the experience of wearing the garment and using the self-reporting tool. Because the sensors need to make sensor-to-skin contact, it was experienced by some participants as being too tight. The interface received positive feedback as being intuitive to interact with, but there was also room for improvement. The *squeezing bar* is inconvenient to use when the hand is occupied. Furthermore, it is not well integrated with the modality of the garment. Immediate feedback is needed for the self-reporting tool to provide a reference to the strength of squeezing. Although the *squeezing bar* was deemed not suitable for integration of the garment, the technique of squeezing as a way of reporting self-perceived stress is utilised in Chapter 5 when developing a smart glove which provides a better embodiment of the squeezing interface and allows for immediate feedback in a simpler way.

4.4.1 Limitations and future studies

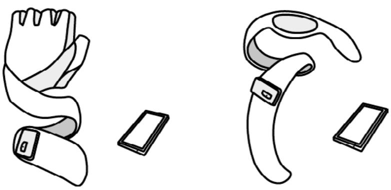
Limitations exist that inform us of directions for future improvements. Although a women's sport top has been used in the design, the design was targeted to men not women. In particular, the placement of the sensors makes it unsuitable for women to wear. Second, only a small number of participants were involved in the user tests who are all males and aged between 24 and 30. Future work should first improve its suitability for mature women, and then include more people of different gender, age and professions to promote generalizability of our learnings. In terms of the methodology of the experiment, we asked the participants to rate the stressfulness of the stressors after they have experienced them so that they can compare them all together. Another possibility would be to ask the participant at the start of the break following each stressor in which case the participant might have a fresher memory of the stressor. Furthermore, in this chapter we only explored one type of stress-reporting interface that uses squeezing. Other types of tangible interfaces might exist that could also engage the person to express stress intuitively. Finally, one should realise that the currently available wearable sensors for physiological stress measurements are still not very reliable. As mentioned by Guribye et al. (2016, p. 9), to sense stress is "very sensitive to inaccuracies or errors in measurements" and prone to a bigger challenge of monitoring human health behaviour. Therefore, when setting up larger studies with wearables that sense stress through biomarkers, it is essential to include the people who wear them in the 'sensing-loop' that will allow them to contest, enrich, or disambiguate the sensor data.

4.5 Conclusion

This chapter presents the process of making a garment that is composed of physiological sensors and includes a tangible user interface to enable the wearer to report self-perceived stress. We explored how to integrate sensors in a garment that can capture physiological data and that is comfortable to wear. A self-reporting tool was made that relies on squeezing as a natural body movement to self-report on stress. We learned that the quality of physiological data can be significantly affected by the contact of the sensor with the skin and body movements of the wearer. Based on people's experience of wearing the garment, results indicate how comfort and style are important considerations that may determine if one is willing to wear a garment or not. We further learned how the use of the self-reporting tool is intuitive but how it should not disturb current activities. Lessons learned from this chapter provide useful insights on how to design wearable partners that are able to sense stress and engage the wearer to report stress intuitively. Note that, in relation to the research described in Chapter 3 on developing partnership genres, this is a technological exploration done in parallel. By connecting both studies in retrospect, the garment and self-reporting tool can be seen as providing the technical foundation of a wearable organ.

CHAPTER 5

Making Grippy: A Smart Wearable Partner to Help Cope with Stress



This chapter describes the design process of Grippy, a smart glove and annotated map on a smartphone, with an overall aim to help people with chronic posttraumatic stress disorder (PTSD) to seek out potential stressful situations and learn to cope with stress by means of exposure training. We introduce the design rationale of Grippy and how its functions are informed by the genres of organs, collaborators and mentors. We describe the design process of Grippy by focusing on practical considerations in crafting its embodiment, behaviour and interactivity. We reflect on the methodology used when making Grippy in particular about the iterative process conducted within an interdisciplinary team. This chapter ends with the discussion and reflection on what we learn about the genres from the practical experience of making Grippy. The next chapter describes how Grippy has been used as a speculative probe to research how people experience wearing and interacting with such a wearable partner in everyday contexts.

5.1 Introduction

We have designed an interactive prototype of a smart glove, named "Grippy", a smart glove and annotated map on a smartphone, with the overall aim to help veterans with chronic PTSD become more aware of stress and encourage them to cope with stress by means of exposure training (Figure 5.1). Smart wearable devices are increasingly used to help people monitor and cope with stress on a daily basis. For people with PTSD who experience stress as a chronic condition, smart wearables are valued that have a presence in day-to-day activities and can help them deal with stress as *partners*. Grippy has been deployed as a speculative probe in the field to investigate how people experience wearing and interacting with such a wearable partner in everyday contexts (See Chapter 6).

The inspiration of Grippy can be traced back to the graduation project by Quaedvlieg (2019). Quaedvlieg described the concept of a smart glove that functions as an interface between veterans with PTSD and a smart vest which can help the wearer to manage the data collected through the vest in real-time and to facilitate communication with the therapist. This project has been part of an ongoing body of work (to which this PhD thesis also belongs) addressing the notion of wearables to support stress management. It was informed by the study done by Li et al. (2021) (conducted in 2017) in terms of how veterans with PTSD coped with daily stress and envisioned the design of smart wearables. Quaedvlieg's work served as a conceptual basis on which we further designed and developed Grippy.

In this chapter, we describe how Grippy is informed by the conceptual framework on smart wearables as partners from Chapter 2, the partnership genres described in Chapter 3 and by the practice of exposure therapy in Cognitive Behavioral Therapy (CBT). During the design process we focussed on practical considerations in terms of the embodiment, system behaviour and interactivity (e.g., functionality, aesthetics, wearability and smooth technical integration of the sensors and actuators). We end by discussing what we have learned about the genres based on the practical realisation of Grippy.

Figure 5.1. The final prototype of Grippy, which includes a glove-shaped version and a strap-shaped version connected to an app on a smartphone.

5.2 Design rationale

In the design of Grippy we drew inspiration from *exposure therapy* to design smart wearables as a partner to initiate exposure self-training in everyday contexts. Exposure therapy is a type of CBT commonly used for the treatment of fear-related syndromes and anxiety disorders, the principle of which is "the conquest of our fears requires confrontation with the things we fear the most" (McNally, 2007, p. 750). For the treatment of PTSD, exposure therapy involves repeated confrontation with traumatic memories in the forms of images, objects, activities and situations (Friedman, 2015, p. 59; Hembree et al., 2003). By doing so, it helps facilitate the emotional processing of traumatic memories and modify the erroneous cognitions that dominate the patients' thoughts, feelings and behaviour. Traditionally, exposure therapy is conducted in clinical environments under the guidance of a psychotherapist. With Grippy, we aim to design a wearable partner that could actively engage people to find out and cope with everyday stress by means of exposure-training exercises they could engage in by themselves (Figure 5.2).

In Chapter 2 we proposed a *conceptual framework* for designing smart wearables as partners for veterans with chronic PTSD which could engage the wearer in an ongoing dialogue to build up an understanding of the stress a person experiences, the situation in which it occurs, and how the wearable can provide support. Grippy has been informed by the framework in the following way. To build up an *understanding of stress* Grippy uses a heart rate sensor to measure physiological stress and uses a gripping interface to assess the subjective experience of stress. An accelerometer has been added to assess a person's physical activity (that–as we will explain later in this chapter–is a relevant source of information to support this particular target group). To have a sense of the *situation*, Grippy has been equipped with a GPS sensor to map out the geographical locations where stress has been experienced. Grippy stores these episodes on the digital map on the smartphone. Pressure sensors and vibration motors integrated in the fabric of the glove allows Grippy to engage in a *dialogue* in a physical way. Grippy has been designed to *support* people to deal with stress in different ways that we will explain according to the three partnership genres (introduced in Chapter 3) in relation to their functions.

Figure 5.2. Storyboard explaining the smart glove functions (left) and the annotated map on the smartphone (right).

5.3 Grippy's functions

In Chapter 3 we argued how partnerships with smart wearables can be designed as *organs, collaborators* and *mentors* and each provides different types of support. Below we will shortly introduce each genre and elaborate on how Grippy's functions have been designed to provide support according to these genres.

5.3.1 Organ: Stress Reminder, Inactivity Reminder and Haptic Interface

Smart wearables as *organs* monitor the bodily changes caused by stress and translate them into externally mediated signals (such as sound or vibration) to help the wearer become aware of stress. The interaction with such wearable organs is reflexive, i.e., triggering a human response without requiring conscious attention. Grippy aims to raise one's awareness of stress by monitoring heart rate levels as a physiological indicator of stress and producing a vibration signal when the heart rate exceeds a particular threshold. When this signal is elicited, the wearer is asked to report on the level of stress experienced at that moment by clenching the fist. The harder the fist is clenched, the more stress is reported. This interaction is designed to be fast and intuitive.

Grippy can help the wearer become aware of stress and to report it intuitively. It does so through the functions of *Inactivity Reminder*, *Stress Reminder* and *Haptic Interface*.

Stress Reminder is a 5-second vibration that reminds the wearer of potential stress arousal triggered by the heart rate sensor when it exceeds 130 BPM. A minimum interval of one hour has been set up to avoid 'over triggering' (see discussion). Upon receiving this signal, the wearer can report on the experienced stress through interacting with *a haptic interface* which is composed of a force sensor located on the palm of the glove and connected to the vibration motor. The wearer can *squeeze* the glove to indicate the level of experienced stress; the harder the squeeze, the higher is the level of stress reported. When doing so, Grippy responds with three patterns of vibration according to the force applied to the palm ('single click' to light squeezing, 'double click' to medium squeezing and 'triple click' to strong squeezing). The design of the haptic interface is inspired by the tangible self-reporting interface (the *squeezing bar*) that we used in Chapter 4. This interaction technique was considered as a promising way to engage people to report self-perceived stress intuitively and compatible with the modality of the glove.

Inactivity Reminder (a 1-second vibration) is intended to remind the person to stay active and explore potentially everyday stressful situations. This function is important because we learned from our previous study reported on in Chapter 2 how people with chronic post-traumatic stress are inclined to stay at home and tend to avoid social contact. It does so by sending out a vibrational signal when the accelerometer senses that the person has taken less than 1000 steps within a two hour timeframe. This signal is intended to be informative thus no action on the device is required.

5.3.2 Collaborator: Challenge Prompt and Comforting Support

Smart wearables as *collaborators* provide guidance in helping a person to manage stress as a purposeful collaborative activity. Smart wearables as collaborators are explicit in their *intentions* to guide a person through a *procedure*. The smart wearable and the wearer *negotiate* about the procedure: when and how interactions on stress management are carried out. Grippy provides support as a collaborator by guiding a person in stress exposure training. This works as follows. Grippy prompts the wearer with a vibration signal to go for a training exercise when it senses by means of its GPS sensor and the stored map data on the smartphone that the wearer is nearby a location that has been experienced in the past as stressful. A person can decide to accept or ignore Grippy's suggestion. When a person accepts the suggestion to go for an exposure training session, Grippy produces sustained relaxing vibrations intended to help a person focus and stay calm until the wearable or the wearer decides it is time to stop the exercise. Wearers can also start a training session on their own initiative.

Grippy will engage the wearer in the collaborative activity of exposure-training. This is made possible by two functions, i.e., *Challenge Prompt* and *Comforting Support*. *Challenge Prompt* works as follows. Once Grippy senses that the wearer is nearby a geographical location where the person has earlier reported to have experienced stress (within a 25-metre radius of the location), it will send a vibration signal (lasting for 5 seconds) to *challenge* the person to revisit that location. The wearer can decide to take on the challenge by pushing *the challenge button* on the glove. When the challenge button is pressed to start a challenge, *Comforting Support* will be activated to provide a relaxing vibration simulating 'deep breathing' to calm down the person during the self-training session, which lasts for five minutes or until the button is pushed again to stop it.

5.3.3 Mentor: Annotated Map

Smart wearables as *mentors* provide guidance by helping a person gain insight about their own ways of experiencing and coping with stress. Smart wearables as mentors engage the wearer in a co-development process where both learn from previous interactions and mature over time. As such, smart wearables as mentors can be perceived as sentient artificial entities which can memorise and learn about people's behaviour across different situations. Grippy provides support as a mentor by educating a person about the situations in which stress has been experienced by visualising these situations on an annotated map on the smartphone. This can help the wearer to reflect on and learn from the historical experience of finding out and coping with stress situations. This map is built up from previous interactions and is therefore unique for each individual.

As shown in Figure 5.2 (right), we use fist-shaped icons of different colours to represent the reported stress in different geographical locations (green icons for low-level stress, yellow icons for mid-level stress and red icons for high-level stress). We use medal-shaped icons to represent the self-training sessions, which is added on the map when the person accepts the encouragement of Grippy to do a self-training exercise (by pushing the challenge button on top of the glove). The medal-shaped icons can replace the fist-shaped icons if on the same location (and will remain on the map). In case the wearer initiates an exercise him- or herself, a medal-shape will immediately be placed on the map. By updating the annotated map in real time, the wearer could gain an overview of the progress of the self-training exercises, and thus be motivated to continue the activity of seeking out and learning to cope with stressful situations.

5.4 Design process

In describing the design process of making grippy we elaborate our main considerations in crafting Grippy's embodiment, behaviour and interactivity.

5.4.1 Embodiment

Designing the embodiment of Grippy involved considering how the electronic components could be integrated in the glove while keeping an eye on its wearability and aesthetics. Several design iterations were conducted that involved sketching, making mock-ups, and creating several preliminary prototypes before arriving at a final version (Figure 5.3).

Figure 5.3. Crafting the embodiment of Grippy. The design process included inspiration sources of Grippy (a, b), conceptual sketches (c, d), Prototype 1 to Prototype 7 (e~k), printed circuit board (PCB) (l), the plastic casing to accommodate the electronic components (m), and embedding the electronics on the fabric.

Wearability and aesthetics

We explored the wearability and aesthetics of Grippy through sketching and making prototypes of different fidelity levels. We chose a glove as a wearable because it provided the embodiment suitable for the squeezing interface we have explored in Chapter 4 and looked at fitness and military gloves as a source of inspiration for its aesthetics (Figure 5.3a and 5.3b). Furthermore, the gesture of squeezing (or making a fist) was also found to be able to enhance people's sense of control and help people feel more determined. Grippy's functions further determined the physical elements the glove needed to include: (i) a cushion on the palm of the hand to buffer the pressure of squeezing, (ii) a plastic case on top to accommodate the Arduino board, the battery and other electronics such as the Bluetooth module and the accelerometer, (iii) a button to start and end an exposure self-training exercise, and (iv) a strap around the wrist to make sure that the heart rate sensor and the vibration motor are closely attached to the skin.

We also explored the ease of use: how Grippy could be easily put on and be taken off, whether it is comfortable to wear for a long time and whether or not it hinders the movement of the hands. We designed two versions of the glove: a *glove-shaped* version (Figure 5.3c) and a *strap-shaped* version (Figure 5.3d). While sketching during the conceptualization phase of the design process, the idea for a strap-shaped glove emerged as an alternative way of wearing gloves that does not hinder the use of the hand as much as a glove version does. Furthermore, the strap-shaped Grippy can be worn on both the right and left hand. For the convenience of description, in the remainder of this chapter and the thesis we use *Grippy* or *the (smart) glove* when referring to the design as a whole, while in the cases where these two versions of prototypes show different characteristics they are described as *the glove-shaped version* and *the strap-shaped version* respectively.

Technical integration

When developing Grippy as a technically integrated device, our concerns were mainly about the selection of electronic components and their placement in the fabrics and how the smart glove and annotated map on the smartphone could form a seamless system. We selected low-cost electronic components that fitted the design requirements. For example, a low-cost heart rate sensor (Pulse Sensor) was selected that provides relatively good data of BPM (beats per minute) when closely attached to the skin. We chose a small-sized vibration motor (model: C1026B002F) that feels comfortable when attached to the fabrics worn on the hand and allows the vibration signals to be felt on the skin. The Grove – Round Force Sensor (FSR402) formed the haptic interface as it is readily available online and compatible with the Arduino boards we used. Some technical features of these components also influenced our decisions regarding their specific locations on the glove. For example, we decided to integrate the Arduino board, the accelerometer, the Bluetooth module and the SD card into a specially designed printed circuit board (PCB) (Figure 5.3l) and accommodate it in a plastic casing (Figure 5.3m) because they do not have to be attached to the skin and need to be well protected from outside influences and wear and tear. The placement of these electronic components is illustrated in Figure 5.4. A Xiaomi Redmi Note 7 smartphone running Android 9 operating system was used to run the state-machine that dealt with the control of the glove. The smartphone hosts the annotated map which was adapted from the Google maps service platform. The connection between the smartphone and the glove is enabled by Bluetooth.

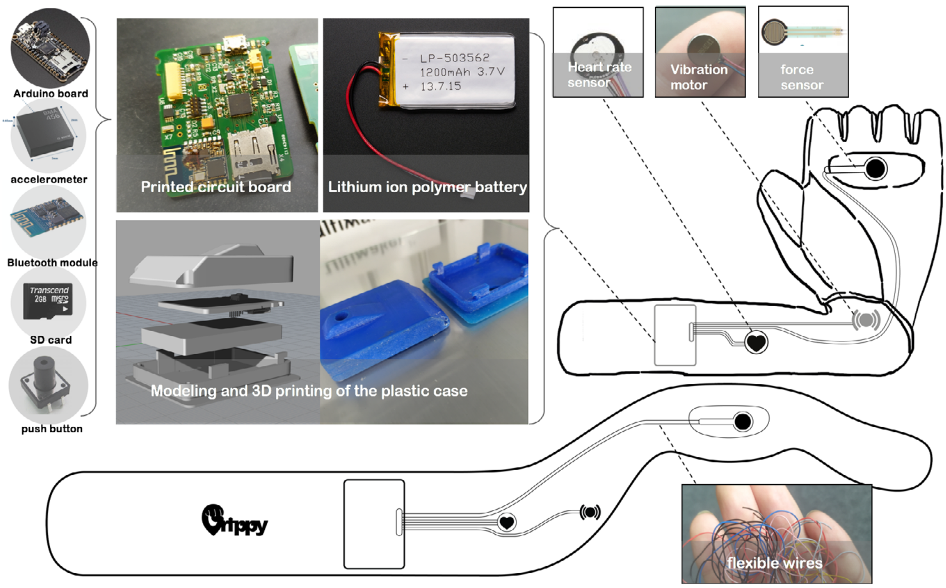


Figure 5.4. Placement of the sensors and other electronic components in Grippy.

5.4.2 Behaviour

Designing Grippy's behaviour involved creating a state-machine for the control of Grippy's actuators and sensors as part of its software architecture (Figure 5.5). We composed vibration patterns by using the library that came with the vibration motor, which allowed Grippy to communicate with the wearer.

State machines, or state-machine diagrams, are commonly used by software engineers to create and describe the behaviour of systems (Bourguet, 2003; Shehady & Siewiorek, 1997). We used a simple version of state-machine diagramms that features states and external events that trigger transitions between states. Figure 5.5 shows the diagram of Grippy. It shows specific values, thresholds and conditions of the sensor and actuators. For example, we determined the trigger of inactivity reminder at less than 1000 steps within a two hour time frame as a threshold for being active or inactive. In comparison, when going for a two hour walk, you would take some 8000 steps according to an activity tracker. The state machine has been implemented in C++. The algorithms[3] of Grippy run on the PCB and the smartphone (Android 9.0).

[3]The algorithms for Grippy can be accessed via this link: https://github.com/id-studiolab/GetAGrip

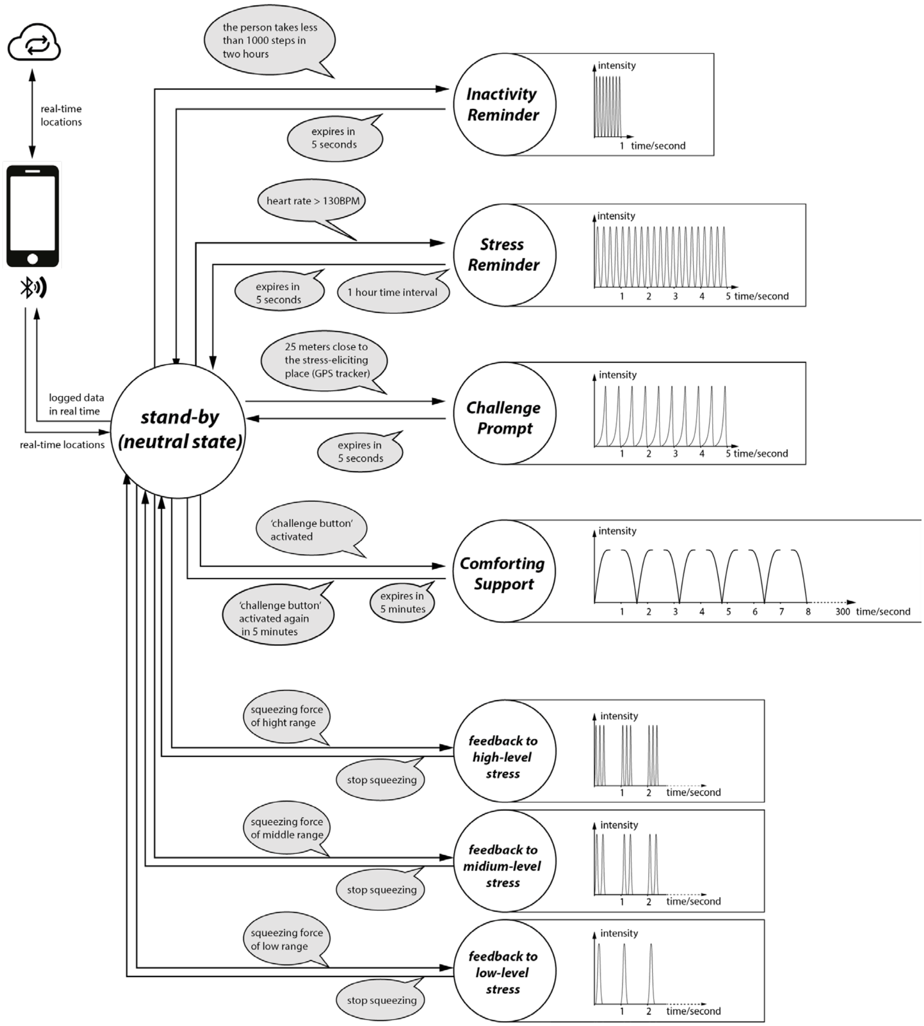


Figure 5.5. State-machine diagram of Grippy as implemented on the PCB and the smartphone. The patterns of the vibrational signals are depicted by means of graphs in which the horizontal axis represents the time and the vertical axis represents the intensity.

We programmed the vibrational signals by adjusting the codes of the library that came with the vibration motor. In the selection of the signals, attention was paid to how these crafted vibrational signals could express the intended message and affective tone as we imagined in the design concept. Visualisations of these patterns are shown in Figure 5.5. The signal used for *Inactivity Reminder* takes the form of a rapid and short vibration intended to activate a person with a sense of urgency. The vibration signal for *Stress Reminder* is intended to simulate the tone of asking the question of “Are you doing OK?”, while not adding to the stress level of the wearer. The signal for *Challenge Prompt* involves a repetitively increasing pattern intended to ‘encourage’ the person to go ahead and take up the challenge. Lastly, the signal of *Comforting Support* mimics the rhythm of slow deep breathing (i.e., inhale, pause and exhale) with the intention to help the person relax.

We chose vibrotactile signals as the actuations because they are private and attract little attention from others in social settings (Hansson et al., 2001). We therefore needed to pay attention to how the signals could be noticed and communicate well without being disturbing. The first three signals last relatively shortly and could be easily ignored. The *Comforting Support* signal was designed to stop by itself after five minutes, but the signal could be stopped earlier by pressing the challenge button.

5.4.3 Interactivity

By *squeezing*, the wearer can indicate self-perceived stress. By *pushing the button* on top of the glove, the wearer can accept and stop a self-training exercise. The annotated map can be accessed via the icon on the smartphone for which a logo has been designed (Figure 5.6).

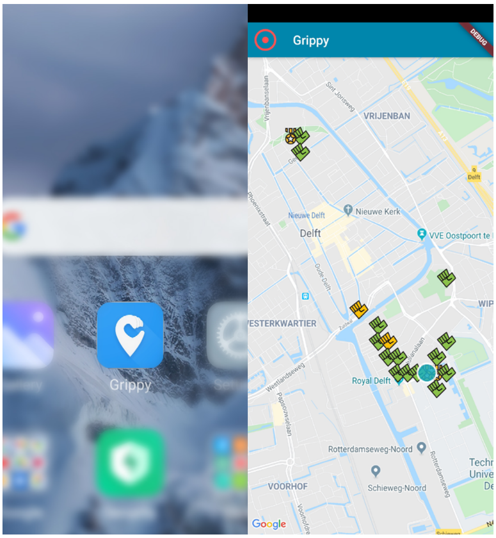


Figure 5.6. Icon of smartphone application (left) and a screenshot of an annotated map (right; the map was generated from a self-test in the field).

Interaction modalities

In the design of the glove, we chose the gesture of squeezing as the main interaction modality (i.e., clenching the fist and pressing fingers in the palm of the hand). Squeezing is one of the gestures that people often do naturally to express feeling stressed, sometimes even subliminally or unconsciously (Lefter et al., 2015; Neff et al., 2010). The gesture of squeezing (or making a fist) can also enhance people's sense of control and help people feel more determined (Fischer et al., 2011; Schubert & Koole, 2009). In our design, we defined three ranges of the sensed force from squeezing, each indicating a particular level of stress. With the help of the intermediate prototypes (Figure 5.3g and 5.3h), we tailored the interaction with the haptic interface so that it allows for minor pressure on the palm without triggering the vibrational feedback (to avoid mis-operation). The switch between the three ranges should be smooth and easy to control given people's average gripping strength. To start and stop a challenge prompt, we added a button (mounted on the PCB) which is firm to press and only accessible through the tip of the finger to avoid false triggering, as shown in Figure 5.7. The interaction design of the annotated app on the smartphone followed a visual interface style commonly used on smartphones with touch-based interaction.

Figure 5.7. Activating the challenge button using the fingertip.

Feedback to squeezing

We used vibration signals to provide immediate feedback to the squeezing action because we learned how hard it was to feel the force applied by relying on the kinesthetic feedback of the hand alone. In Chapter 4 participants also reported the need for immediate feedback to know how much force they are applying to the palm when interacting with the *squeezing bar*. The vibrational feedback takes the form of short pulses that feel like making a *single click*, *double click* or *triple click* in response to *low*, *medium*, or *high* levels of reported stress. Figure 5.8 shows the scenario of interaction with the haptic interface. The action of squeezing immediately adds a fist-shaped icon on the annotated map (the colour of the icons is determined by the strength of squeeze; the colour changes from green to yellow and red as with the increase of the force applied to the palm when squeezing).

Figure 5.8. Intersecting with the haptic interface of Grippy (the glove-shaped version) by squeezing.

5.4.4 Grippy in relation to the earlier concept of Quaedvlieg

Grippy differs from the original concept of Quaedvlieg (2019) in the following aspects. First, the two designs focus on different contexts in which smart wearables as partners could help veterans with PTSD (change in focus). Grippy is conceptualised as a partner to help people train themselves in stress management in everyday contexts, instead of facilitating patient-psychologist communication (as the focus of Quaedvlieg's work). Second, the components of the wearable systems and how they communicate are different (change in system). Grippy is a wearable system composed of a smart glove and a phone application (the glove is the main body of the design that functions as both a sensing tool and an interface). In the design of Quaedvlieg, the glove is considered as an interface connecting the vest to the wearer. The idea was that the user could view the information collected by the vest by holding a smartphone using the hand wearing the glove, but no information would be stored on the phone (the screen would go blank when the wearer would let go of the phone). Next to this, the particular interaction has been altered (change in interaction). In Quaedvlieg's design, stress was intended to be sensed through the tightness of the glove's wristband (via manual adjustment of the belt around the hand) and the gesture of squeezing would be used to tailor the activation time of the sensor, while in the design of Grippy we use strength of squeezing as a way of reporting stress (See Section 5.3 for detailed explanation on this function). Finally, Grippy is a fully functional prototype (while Quaedvlieg's design is conceptual), which invited engineering challenges and prompted new design choices during the development (engineering challenges that prompted new design choices). Engineering challenges that emerged in the implementation of Grippy includes the placement of the sensors, actuators, microcontroller (Arduino board) and the battery, algorithms to activate the sensors and actuators, and to represent the sensor data (on the smartphone). To address these challenges, further adjustments in the design were made given the feasibility of the technologies. For example, a printed circuit board (PCB) was used to integrate and scale down the size of electronic components, which led to the design of a plastic casing located on the back of the hand. The button to initiate a self-training session (the challenge button) was located on the PCB (the back of the hand) so that it can be pressed firmly by the fingertip.

5.5 Methodological reflection

We reflect on the methodology used when making Grippy in particular about the iterative process conducted within an interdisciplinary team.

5.5.1 Iterative design process

Based on the sketched concepts that provided a general direction, an iterative process was followed where we continuously evaluated and adjusted Grippy's embodiment with a focus on the integration of the electronic components in the fabrics and the impact this had on aesthetics and wearability (Figures 5.3e to 5.3k). For example, Prototypes 1 and 2 (Figure 5.3e and 5.3f) were mock-ups to help us evaluate the gloves' fashion styles and comfort. Prototypes 3 and 4 (Figure 5.3g and 5.2h) provided physical foundations to test the technical performance of the electronics as located in different parts of the glove; Prototype 5 (Figure 5.3i) was used to test whether the electronics on the glove responded correctly to the algorithms of the smartphone application.

We tested the technical performance of these electronic components in the lab to make sure they achieve functions as envisioned in the design. For example, we checked the sensed signals of the heart rate sensor with it attached to different locations on the hand while making different movements and gestures. As a result, we decided to locate the sensor on the inner side of the wrist so that it would not hinder the use of the hand while still getting relatively stable data (although we could not completely avoid the disturbance caused by the hand movements). Note that the heart rate sensor is inherently not a reliable method to sense stress when attached to the body on the move and applied as the only source of data, as we have discovered in Chapter 4. It is therefore, in the design of Grippy, the heart rate sensor was applied as a trigger of a stress reminder that communicates the intention of "are you OK?" (rather than a stress 'indicator' or 'alarm'). The performance of these electronics helped us to decide on the specific measures and thresholds of the electronics in the integrated algorithms. The final prototypes (Figure 5.3j and 5.3k) are functional prototypes that we used as speculative probes in the study reported on in Chapter 6.

The three form elements of interaction design are closely interrelated in the design process, with each element depending on the others in expressing a design's overall manifestation. For instance, Grippy's temporal form (i.e., the various vibration signals) is only perceivable through the vibration motor embedded in the glove; the interaction gestalt of squeezing for stress-reporting depends on the texture of the fabrics and the intensity of the vibration feedback. This dynamic and composite characteristic of the form factors requires designers to work back and forth between the concept and technical details, and between the design visions and how they are actually realised.

Some design decisions were informed by the intermediate outcomes of the design process. For example, the algorithms of the vibration feedback to the gesture of squeezing can only be tested and adjusted when the haptic interface is realised in its physical form (Figure 5.3g - 5.3k). Prototypes 3 and 4 (Figures 5.3g and 5.3h) helped us to realise that simply assembling the electronics on the glove would occupy too much space and disturb the use of the hand, which led to the decision to use a customised PCB to reduce the size of the plastic casing. In addition, some technical problems arose that required us to find alternative solutions. For instance, the *Stress Reminder* signal was often triggered erroneously because of body movements that interfere with the sensors. Therefore, based on our testing with the heart rate sensor, we combined a relatively high BPM threshold value (130 BPM in this case) with a minimum interval of one hour. In this way, the wearer would not be bothered by false signals. Extensive testing is necessary to establish the performance of the prototype in this combination of sensors and actuators. It might require adjustments and perhaps another sensor if this becomes available.

5.5.2 Making Grippy with an interdisciplinary team

Grippy is a result of collaboration within a multidisciplinary team including an interaction designer (the PhD researcher), an electronic engineer, a software engineer, a firmware engineer, and a fashion designer. The PhD researcher, who also took the project lead, had gained basic knowledge and skills from each of these domains to be able to communicate with other team members. Visualisation tools proved to be particularly helpful for communicating with people from different disciplinary backgrounds. For example, state-machine diagrams were useful when explaining the complex functions of Grippy to the software engineer in an understandable way that helped him to translate *functions* specified on the level of *use*, into algorithms. With the help of the sketches, the interaction designer and the fashion designer could discuss the kinds of fabrics that might fit with the concepts presented and which techniques could be used to achieve them. While being involved in the design process and taking the lead in the project of developing Grippy, the PhD researcher took mixed roles of a designer and a facilitator. Further discussion on the multiple roles taken by the PhD researcher across different design and research activities and the impact of these roles on the work reported in the thesis can be found in Chapter 7 (Section 7.1.3).

5.6 Discussion and reflection

The previous sections describe how we gave form to Grippy in terms of crafting its embodiment, behaviour and interactivity. In this section, we reflect on the extent to which Grippy has been realised as an organ, a collaborator and a mentor by referring to the vocabulary proposed in Chapter 3. We also discuss the limitations we have encountered in the making of Grippy.

5.6.1 Reflection on the vocabulary of the three genres

Based on the experience of having made Grippy which challenged us on the level of technical realisation, we will further reflect on how the realisation of Grippy connects to the vocabulary of the three genres presented in Chapter 3 from a retrospective and a designerly perspective. Table 5.1 provides a summary of the key learnings from this reflection and can be used as a reading aid where keywords or sentences can be seen back in the following text. Note that these genres are embodied in the design of Grippy as a preliminary attempt. It can be imagined that people might perceive or experience Grippy in different ways than we intended. Whether and how Grippy will be experienced by the actual wearers is the focus of Chapter 6. In this section we discuss to what extent Grippy's functions matched the concepts in the vocabulary of the genres. We show that the design of Grippy's functions has characteristics of more than one genre. This discussion could help designers make conscious choices regarding the design rationale in relation to the actual design manifestation and intended functionalities.

When reflecting on Grippy's manifestation, Grippy can be described as an *organ* whose actions are *translations* of stress-related data into actuations when sensed data is above certain thresholds. It is *ephemeral* as it acts immediately if the stress levels are higher than the set thresholds. Grippy's haptic interface is intended to trigger *reflexive* interaction; the wearer reflexively squeezes when sensing a vibration from Grippy, where the strength of the squeeze is indicative of the amount of stress experienced. The wearer does not have to think about this at all. So Grippy's design matches all aspects of an organ.

Furthermore, we will check to what extent Grippy also fits the characteristics of a *collaborator*. Grippy *intentionally* communicates to the wearer with its signals. Retrospectively, we now see that Stress Reminder and Inactivity Reminder (which were first introduced as functions inspired by the genre of organs) also add to the attribution of Grippy as a collaborator. In particular, the signal produced by the heart rate sensor is also intended to communicate "are you OK?" and the signal from the activity data is also intended to communicate "come on and get active". With respect to the *procedural* and *negotiable* qualities, we point out that both Grippy and the wearer can take the initiative to start or end an exercise, to adhere to, ignore, or override the guidance of Grippy. Therefore, Grippy meets all characteristics of a collaborator.

In the current design, Grippy does not display characteristics of a Mentor yet. Overall, this is due to the complexity of the PhD project, as discussed in Chapter 7. In terms of the vocabulary, Grippy cannot be called *sentient* as it does not have "a similar sensitivity to that of humans or other living beings", nor does it have explicit knowledge about dealing with stress or about mentoring styles. In addition, Grippy doesn't have the capability for "growing wisdom" (the *maturing* quality). No machine-learning algorithms have been used to enable Grippy to learn from historical interaction with the wearers. With respect to *co-development*, Grippy includes an annotated map of the locations where the wearer seeks out and copes with stressful situations. That annotated map can serve as a means for the wearer to gain more insights in what triggers stress and to motivate the wearer to be regularly and timely engaged in the activity of self-training. In conclusion, Grippy, in its current form, cannot be called a Mentor, but might be taken as an 'adaptive' collaborator.

Retrospectively, we realise that Grippy is somewhere in between an organ and a collaborator, and even satisfies to some extent the co-developing criterion of a mentor. In this sense, it can be called a 'collaborative' organ. So, in general, we come to the understanding that a smart wearable can have the characteristics of two or more genres at the same time. In terms of intelligence, this is in line with the notion that going from organ to collaborator and from collaborator to mentor requires more complex forms of artificial intelligence to be designed into the system.

Table 5.1. Formgiving Vocabulary in relation to Grippy's design.

Genres	vocabulary	Does Grippy fit with the vocabulary of the genres?
Organs: smart wearables that can translate sensor readings from the body and the environment to observable signals that can help the wearer to become aware of their behaviour, and to reflexively react to these situations in an appropriate way.	**Translational:** how the smart wearables translate stress-related signals into other sensory modalities in meaningful ways	Yes. The sensor data (the heart rate and steps) is translated into observable signals (vibrations).
	Ephemeral: the smart wearable acts as an immediate response to a person's varying stress levels	Yes. When Grippy senses stress levels about the threshold, it immediately gives off signals.
	Reflexive: how smart wearables as organs enable a reflexive kind of interaction	Yes. The wearer reflexively squeezes in response to the signal and the strength of squeezing is indicative of the amount of stress; there is no need to (over)think.
Collaborators: Smart wearables that allow the wearer to deal with their behavioural issues, in a collaborative way.	**Intentional:** smart wearables are explicit about their intentions to engage people in a collaborative activity	Yes. The signals of Stress Reminder and Inactivity Reminder, and Challenge Prompt have intentional meanings ("are you doing OK?", "come on and get active" and "would you like to take up a challenge?").
	Procedural: smart wearables are able to engage the person in dialogues to achieve their (shared) goals	Yes. Three phases of the collaborative activity are involved: • start of a self-training exercise by pushing the challenge button (the starting point); • going through the self-training exercise with the support of Grippy (the middle sequence); • end of the self-training by pushing the button again or when the vibration expires (the end point).
	Negotiable: The intention and inner programming that initiate, sustain and terminate particular actions of the smart wearable can be influenced by the wearer in a continuous dialogue or feedback loop	Yes. Grippy allows for three kinds of negotiation in the self-training exercise: • the intentions of Grippy can be ignored; • self-training sessions can be terminated by pushing the Challenge button (the wearer overrides Grippy); • The wearer can initiate a self-training session without the prompt of Grippy by pushing the challenge button.

Mentors: Smart wearables that have the wisdom and the sensitivity to teach their mentees, and are able to learn from previous interactions and can therefore show flexibility in the support they provide.	**Sentient:** the smart wearable having the wisdom and sensitivity to mentor	No. Grippy does not have explicit knowledge about dealing with stress or about mentoring styles.
	Maturing: the smart wearable is flexible by learning from the historical experiences with the wearers	No. Grippy's behaviour lacks the machine-learning algorithms needed for "growing wisdom".
	Co-developing: both the smart wearable and the wearer learn from each other over time	Yes, somewhat. The annotated map can serve as a means for the wearer to gain more insights in what triggers stress and to motivate the wearer to be regularly and timely engaged in the activity of self-training.

5.6.2 Limitations

Despite our efforts to make Grippy with a high quality of finish, technological limitations might still exist that hinder its deployment in real life. The haptic interface may disturb the use of the hand. At this point, the *strap-shaped* version shows advantages over the *glove-shaped* version as it can be switched into a strap with the haptic interface wrapped around the wrist. The plastic casing (50x60x10 mm, placed on top of the glove) is still too bulky and this could compromise the wearability of the prototypes. To shrink it even further, more engineering efforts are needed to minimise the number of electronic components and to distribute them more efficiently. A flexible PCB in combination with a more flexible casing would also improve wearer comfort. The prototype's visibility may inhibit daily use. In this sense, the *strap-shaped* prototype might suit people who do not want Grippy to be seen because it can be hidden under the sleeve when switched into a strap. In addition, the prototypes are not washable. This may raise hygiene concerns after being worn for days.

Caution needs to be taken about when and how to introduce Grippy to people with PTSD. We chose to use geographical location data for marking potentially stress-eliciting situations. However, stress can also be caused by particular events that are not associated with a specific geographical location, such as unplanned social encounters, and in particular for people with PTSD, flashbacks of traumatic memories. Evidence shows that avoidance is an effective strategy employed by people at very early stages of recovering from traumatic events (Ehlers & Steil, 1995). Asking people to be exposed to traumatic memories could disrupt this natural recovery process (Bisson et al., 2009; Ehlers & Clark, 2003). It is important to ensure that Grippy approaches and encourages people at a pace that they feel comfortable with and that they are confident about being exposed to daily stressful situations. For this purpose, mental healthcare professionals should be involved to evaluate the benefits and risks of Grippy, provide guidance about its deployment, and offer one-on-one psychological support when needed. After all, the aim of Grippy is not to replace psychotherapists but to provide complementary support in daily situations when their help is unavailable.

5.7 Conclusion

In this chapter, we described the design rationale and process of making Grippy, a wearable partner aiming to encourage and guide people with PTSD through exposure self-training in everyday stressful situations. We elaborated on how the design of Grippy was inspired by the practice of exposure therapy in CBT and driven by the conceptual framework and the vocabulary of designing wearable partners. As for making of Grippy, we elaborated on our design considerations when crafting embodiment (the physical form), behaviour (the temporal form) and interactivity (the interactive gestalt) of Grippy.

We encountered numerous difficulties in the realisation of Grippy; both in creating and integrating sensors that reliably and accurately measure the bodily status of the wearer, as well as in creating and integrating the actuators that allow for unobtrusive interaction with the wearer. To design the haptic interface, specific efforts were taken to craft the vibrational feedback that is meaningful and intuitive to keep the person in an interactive loop, resulting in three patterns of vibration (i.e., single click, double click and triple click) in response to the strength of squeezing. It requires an interactive process and an interdisciplinary team to visualise possible forms of the design, to conceptualise new ways of interaction and to integrate electronics into the fabrics. Of course, some things did not work out as we expected. For instance, the integration of electronics (regardless of the use of the PCB) make the glove a bulky thing to wear. The functional stability is also a challenge: false signals might be triggered due to inaccuracy of sensors due to friction of the wearable on the body when the wearable is worn continuously in everyday contexts. Based on these reflections, our work coincides with the activities in the field of human-wearable interaction that try to attract researchers from many different disciplines, such as, design, materials engineering, mechanical engineering, electrical engineering, computer science, artificial intelligence and psychology.

We discussed how the resulting prototypes of Grippy could be described in terms of the formgiving vocabulary underlying the genres of organ, collaborator and mentor. In retrospect, Grippy can be described as an organ as well as a collaborator, and has the potential to be interpreted as a mentor (for engaging the wearer in a co-developing process). We learned that Grippy shows potential functioning as an organ that could engage the wearer to report self-perceived stress intuitively. The signals to remind the person of arising stress and immobility also add to the interpretation of Grippy as a collaborator since they express semantic meanings and trigger intentional communication with the wearer. In addition, as a collaborator, Grippy is designed to encourage the wearer in the self-training exercise while still allowing the wearer to ignore the encouragement, or to end or start a self-training session on their own initiative. As for mentors, the characteristics of this genre have not been fully implemented in Grippy; its behaviours (actuations) are relatively simple and it does not adapt over time. The data for learning over time is available in the form of the annotated map. However, how and when to trigger the wearer's reflection using the app needs to be further investigated in a field study.

In one word, Grippy can be considered as a collaborative organ. As discussion points: would it make sense to consciously design a "collaborative organ" or a "mentoring organ"? Isn't that the whole idea of having smart wearables to support people in behavioural issues? In short, should all smart wearables to support people in behavioural issues always be at least an organ? The functionalities of a collaborator could be built on top of the functionalities of the organ, and could later be further developed into a mentor.

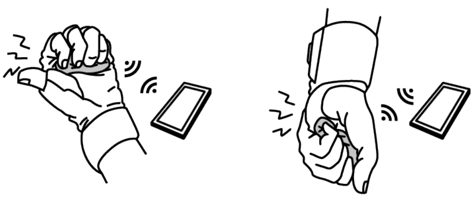
Overall, we conclude that the trajectory from conceptualisation to realising an independently functioning interactive artefact with a high quality of finish that is suitable to be used in everyday contexts, is a difficult and long process. It requires integrating physical materials, electronics and software effectively, carefully aligned with use and experience concerns. It further requires close collaboration within a multidisciplinary development team and an iterative way of working. In the next chapter Grippy will be used as a speculative probe to gain first-hand experience of people who wear and interact with it in real life.

Acknowledgements

Special thanks go to the development team of Grippy, Aadjan van der Helm (electronics), Nirav Malsattar (programming), Martin Havranek (electronics), Elvis Andrade Borges (app programming), Remy van Rooijen (PCB design and hardware), Linda Plaude (textile design), who have contributed their expertise and effort in the realization of Grippy.

CHAPTER 6

Get a Grip on Stress with Grippy! A Field Study to Understand Human-wearable Partnerships in Stress Management



This chapter is adapted based on a manuscript submitted to the International Journal of Design. Some changes have been made to the original manuscript in alignment with the overall reflections presented in Chapter 7.

In this chapter, we report on the deployment of Grippy in the field as a speculative probe to learn more about how people experience wearing and interacting with it during the day and how they experience the support it was designed to provide. We introduced Grippy to six participants (four master students and two university employees) and asked them to wear it for five successive days. Participants were interviewed about their use experience of Grippy during and after these five days. Qualitative data collected from the interviews was interpreted from two perspectives. First, we look into how interaction with Grippy was perceived, how Grippy fit in the physical and social contexts of the participants' daily lives, and how wearing and interacting with Grippy over the days promoted change in how people coped with stress. Second, we analyse to which extent Grippy has been experienced to be an organ, a collaborator and a mentor. In particular, we reflect on the design issues that led to the mismatch between our design intentions and people's actual use experiences. We discuss how these results have deepened our understanding of human-wearable partnerships for stress management, and the usability issues that might hinder expression and acceptance of smart wearables that are designed as particular genres of partnerships. We end the discussion by reflecting on the implications of smart wearables as partners in mental healthcare.

6.1 Introduction

The increased capabilities of wearables to make sense of measured bodily and behavioural signals corresponding to stress and communicating this back to a person (Niknejad et al., 2020) opens up opportunities for developing smart wearables as partners in stress management. Smart wearables designed as partners enable new ways of collaborating with our clothing, garments or accessories that were hitherto impossible. The characteristics of smart wearables—being continuously present as a garment, involving the human body as part of the dialogue and providing support whenever possible and in ways other products cannot—make smart wearables a potential partner that can provide valuable aid to people in dealing with everyday stress. The dot on the horizon for this thesis is to help veterans with posttraumatic stress disorder (PTSD), who experience stress as a chronic and potentially overwhelming condition. The aspect that stress hinders them in their daily life activities, makes this an interesting target group to investigate the concept of smart wearables as partners. We have set out on studies to (a) explore a conceptual understanding of this idea (Chapter 2), (b) establish a vocabulary to describe different types of expression of such a wearable partner in interaction (Chapter 3), and (c) learn how to realise such wearable partners (Chapters 4 and 5).

Chapter 2 proposes a *conceptual framework* for designing smart wearables as partners to help veterans with chronic PTSD cope with stress in daily contexts.

This framework considers how smart wearables can be designed as partners that consider both the person and the situation so as to provide appropriate support. The framework is informed by the technological capabilities of smart wearables concerning their sensing and actuation, and inspired by the kinds of partnerships that people may have with humans, animals and also with technology. We conducted a qualitative study and a co-design workshop with veterans with chronic PTSD to substantiate the framework based on their lived experiences of dealing with stress and their imaginations of smart wearables that could help them in the future. From this study and workshop we distilled qualities such partnerships should have.

Taking this conceptual framework as a starting point we developed a *formgiving vocabulary*, presented in Chapter 3. This vocabulary is composed of three 'genres' of human-wearable partnerships, namely *organs*, *collaborators* and *mentors*. *Organs* refer to the smart wearables that translate sensed signals into observable signals so as to help the wearer be more aware of the situation and able to deal with it reflexively; *collaborators* can engage the person in collaborative activities through their expressed intent and negotiable interactions; and *mentors* are smart wearables that have the 'wisdom', the sensitivity to teach the wearers (mentees), and the ability to learn from previous interactions which enables them to show flexibility in the support they provide.

The conceptual framework and the formgiving vocabulary led us to the design of a wearable partner, i.e. Grippy, presented in Chapter 5. Grippy is a smart glove equipped with an accelerometer, a heart rate sensor and a force sensor to sense one's activity status and physiological and self-reported stress, and a vibration motor to provide tactile signals and feedback. An app on a smartphone connected to the smart glove provides an annotated map that visualises where stressful episodes have been experienced. See Figure 6.1 for an impression. Grippy embodies two genres of wearable partners (i.e., *organs*, *collaborators*) and, to some extent, the genre of a *mentor*. Below we summarise which functions of Grippy relate to these particular genres. For more details please refer back to Chapter 5.

As an *organ*, Grippy is designed to help the wearer become aware of stress and deal with it reflexively. The Stress Reminder function that is triggered when elevated heart rate levels are sensed, is designed to ask the wearer to report his or her stress by squeezing the haptic interface, integrated in the glove. Its Inactivity Reminder function that is triggered when the accelerometer senses that the person has been immobile for a while, is intended to encourage the wearer to stay active during the day. We have added this function because we learned from a previous study (Chapter 1) that veterans with PTSD tend to stay at home to avoid situations that might trigger stress and therefore may need some encouragement to go outside in order to practise. As a *collaborator* Grippy is designed to encourage the wearer to do self-training exercises. Grippy's Challenge Prompt function is activated when Grippy knows the person is approaching a location where he or she has previously reported stress and an exercise could be useful. Its Comforting Support function is designed to help the wearer relax during the exercise by providing soft rhythmic vibration signals. As a *mentor* Grippy is designed to allow the wearer to reflect on previous stressful experiences in order to learn from it. The Annotated Map function on the smartphone shows locations where earlier reports on stress have been given and self-training exercises have been conducted. Reflecting on this data can help the wearer gain insight into what triggers possible triggers of stress while also motivating the wearer to engage in self-training exercises.

As it is the ambition to design smart wearables as partners, we need to better understand how such a smart wearable is experienced when being worn and interacted with during the day. We therefore deploy Grippy as a speculative probe in the field. In the interpretation of people's experiences, we refer first to the Objects with Intent framework (Rozendaal et al., 2020) as an analytical lens (Section 6.3.1). The Objects with Intent (OwI's) framework has been constructed to understand how everyday things are experienced as partners by examining how people frame and experience things as partners. In particular, the OwI framework makes researchers reflect on the meanings objects with intent elicit, the interactions they afford within particular contexts of use and how people's behaviours and experiences may change as a result of the interaction. In Section 6.3.2 we deepen our analysis by coming back to the formgiving vocabulary and the genres of wearable partnerships. We discuss our work in Section 6.4, and draw conclusions in Section 6.5. We now first describe the field study (Section 6.2).

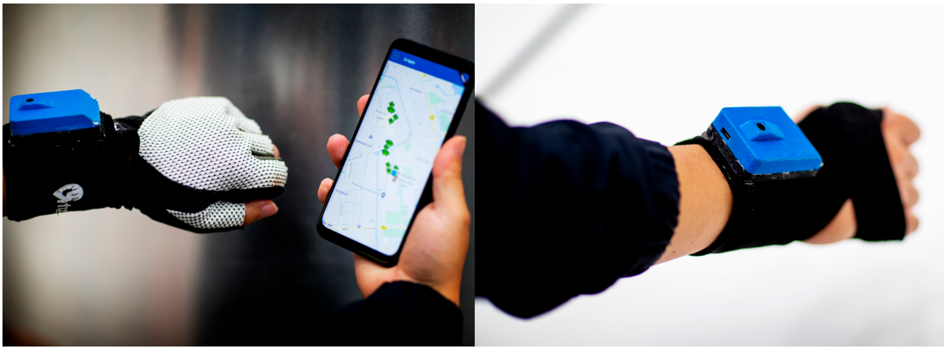


Figure 6.1. The glove-shaped version of Grippy and the smartphone application (left) and the strap-shaped version of Grippy (right).

6.2 Field study

With Grippy as a speculative artefact, we conducted a field study to investigate *how people experience wearing and interacting with a smart wearable during the day* (RQ4). The study was reviewed and approved by the Human Research Ethics Committee (HREC) of Delft University of Technology. The prototypes of Grippy had been inspected by the Health, Safety and Environment advisor appointed by Delft University of Technology before they were deployed in the field.

6.2.1 Participants

We recruited four master students and three university employees as participants, one of which dropped out of the study after two days of wearing Grippy. Table 6.1 shows an overview of the six participants. As can be seen from the table, participants have a Chinese, Indian or Italian nationality, and included mostly women. All the four master students, here called Alice, Bella, Caroline, and Diane, majored in Design and were finishing their graduation projects during the time of this study. Emily was a second-year PhD student with a background in design engineering. Frank was a visiting researcher at the time of this study who obtained his master degree in design engineering. None of the participants reported having been diagnosed with a stress-related mental illness.

6

Table 6.1. Participants information.

Code name	*Age*	*Gender*	*Education / Profession*	*Nationality*	*Assigned version*
Alice	25	female	Master student	Chinese	Glove-shaped version
Bella	27	female	Master student	Italian	Strap-shaped version
Caroline	23	female	Master student	Chinese	Strap-shaped version
Diane	22	female	Master student	Chinese	Strap-shaped version
Emily	28	female	University employee	Chinese	Glove-shaped version
Frank	25	male	University employee	Indian	Glove-shaped version

6.2.2 Procedure

At first, we arranged an introduction meeting with each participant where we introduced the purpose of the study and functions of Grippy. Informed consent was obtained from all participants. The participants tried out Grippy to become familiar with its functions under the guidance of the researcher (the PhD researcher). A box was given to the participants to take home with them, including the prototype, a smartphone with the app installed, and a notebook with instruction manual (See Figure 6.2). Alice, Emily and Frank were given the glove-shaped version of Grippy. Bella, Caroline and Diane were given the strap-shaped version. Mid-term meetings were arranged with the participants once or twice during the five days to check how things were going and if there were any problems with the prototype.

The study ended with a final interview lasting between one and two hours. The interview was divided into three sessions with questions focusing on (1) general experience of using Grippy for several days, (2) specific usability and user experience issues, and (3) the extent to which Grippy was experienced to be supportive in stress management (see the interview script in Appendix 3). The mid-term meetings and interviews were audio-recorded and transcribed afterwards.

Figure 6.2. Impression of the prototype package delivered to the participants.

6.2.3 Data analysis

At the start of the analysis, the PhD researcher read through all the transcripts to gain an overview and familiarity with the content. In total, 284 initial quotations were identified as being interesting and relevant by following an open-ended qualitative research method (Hsieh & Shannon, 2005). We applied the "Objects with Intent" framework (Rozendaal et al., 2019) as an analytical lens to organise these quotations under three themes, i.e., *framing*, *embedding* and *transformation*. *Framing* involves understanding how Grippy is interpreted and interacted with as a smart wearable. *Embedding* addresses the question about how the use of Grippy integrates in people's everyday activities and daily routines. *Transformation* refers to how interacting with Grippy may change people's behaviours and experiences, and thereby sheds light on how Grippy can provide support. All the interview data was coded through the software Atlas.ti™ and later on transferred into an Excel™ file which can be accessed through an online repository system[4]. After this, we have looked through the results of the analysis above and reflect on them by referring to the vocabulary of the three genres (as proposed in Chapter

[4]The quotations selected and organized according to the themes can be accessed through this link: https://doi.org/10.4121/14672715

3). This reflection has led us to an understanding of to which extent Grippy has been experienced as an organ, a collaborator and a mentor. The findings suggest that some functions of Grippy match our intention of design, but others do not. Interpretation of the mismatch and future improvement are also discussed.

6.3 Results

6.3.1. Objects with Intent Framework

In this section we present the results of the study according to the themes of framing, embedding and transformation. Table 6.2 shows a brief overview of the classified insights for each theme.

Table 6.2. An overview of the concepts with the identified topics.

Framing	*Embedding*	*Transformation*
Garment Interactive system Therapeutic device Agent	Situated use Social interaction	Developing awareness Objectifying stress Stress release

Framing

From the results of the analysis, we found that Grippy was perceived and interacted with in multiple ways concurrently. Participants framed Grippy in terms of being a *garment*, an *interactive system*, a *therapeutic device*, and as an *agent*. We describe how different framings of the wearable gave rise to particular concerns.

Garment

When describing Grippy as a garment, participants commented on its visibility and wearability. Concerning visibility, the glove-shaped version of Grippy received mixed opinions on its appearance which influenced their preferences to wear it in the company of others. For example, Alice and Frank described it as "cool," "cyberpunk," "sporty" and "futuristic." They felt positive to wear Grippy in public and show it to others. However, Emily found the design of the glove-shaped Grippy "manly" and initially felt reluctant to wear it. Diane commented on how the blue plastic casing on top of the glove made it "stand out" and "attract people's attention easily." This made her feel hesitant to wear Grippy. As for wearability, all participants expressed how the glove got in the way when they needed to use their hands, for example while typing or cycling. Caroline appreciated the design of the strap-shaped version of Grippy because she could wrap up the haptic interface around the wrist so that she could use her hand freely, as illustrated in Figure 6.3. Still, both the glove-shaped and the strap-shaped versions were considered too bulky because of the plastic casing, which could get in the way when they put on or take off their coats.

Figure 6.3. An example of how the *strap-shaped* version of Grippy can be worn with the haptic interface wrapped up around the wrist.

Interactive system

Grippy was also described by participants as an interactive system composed of the glove and the smartphone application, which raised issues about usability and enjoyment in use. The glove received mixed opinions regarding its interactive features. Some participants found it intuitive and pleasant to interact with the glove through the haptic interface. Caroline recalled that she played with Grippy more often than actually using it for reporting stress. She said that "it's just fun, I cannot help but keep pressing it… because the feedback is in real time." Participants also commented on how the button on top of the blue plastic casing felt unnatural and cumbersome to operate. Alice, Caroline and Emily complained that it took extra effort to accept a challenge suggested by Grippy or start a challenge yourself since it required keeping eyes on it and required the use of the other hand to push the button. Alice commented that the action of pushing the button did not feel very natural, and said "You normally wouldn't push a button precisely when you are super stressed."

As for the different vibration signals Grippy produces, most of the participants found it difficult to distinguish them from each other. Diane sometimes could not tell the difference between the Inactivity Reminder and Stress Reminder while Emily said that all vibrations felt the same to her, and she was "always confused by what Grippy wanted when it vibrated." Concerning the annotated map on the smartphone, participants were not actively using it. Alice, Diane, Caroline and Emily said that they had little interest in the app because it only provided information about where they were, or had been. Alice said that her life was already overloaded with information coming from apps on her smartphone and therefore decided to ignore it. Caroline mentioned that carrying a second smartphone with her felt like a hindrance and for this reason she normally left it in her bag.

Therapeutic device

We also noticed that participants perceived Grippy as a therapeutic device which reflects their needs for technological support in stress management. Given its therapeutic connotation, Grippy was not fully embraced, as few participants considered themselves needing help in dealing with stress. For example, Diane described herself as an optimistic person who paid little attention to when and how she felt stressed. She mentioned that Grippy "doesn't feel like something that is for ordinary people like us." Emily made a similar statement by saying that "normal people don't wear this kind of glove." Furthermore, we received opinions regarding why Grippy is inappropriate in certain situations. Alice said that she would only wear it when she knew she was (or was going to be) stressed, and would take it off when she was at home, going shopping and on weekends when she would be relaxed. She described Grippy as a sort of "symbol of stress": Not wearing Grippy made her feel relieved as if she put away her stress together with the glove. When asked why Grippy was not needed, Bella explained that Grippy did not fit with her personality saying that: "If you ask my friends, they will tell you I am never stressed because I always look like everything is fine." This collection of statements indicate how stress, and the need for a device to help you deal with stress, can be a sensitive topic that can impact the willingness to use a new technology.

Agent

Participants also described Grippy as an agent that you can communicate with and keep you company. When asked to describe the character of Grippy as a kind of personality, two participants (Alice and Emily) brought up that Grippy reminded them of a dog. Alice said Grippy was like a dog in that "[it] always listened to you and always responded to you even though you cannot have in-depth communication with it." Both Alice and Emily commented that the cushion on the haptic interface reminded them of the pads on dogs' paws. "It's warm and gives an animal-like or alive feeling," Alice added. Emily commented that, as a dog, Grippy was "too active and asked too much attention from her." Grippy was also described as a "companion." Caroline referred to Grippy as someone "between a friend and *another self*" who she could trust and share emotions with. She explained that "if a friend tells you something like this [that you are stressed now], you might feel a bit offended or it's uncool but I feel less uncomfortable when being told by Grippy." Bella referred to Grippy as a friend who you can always call and made her feel just a bit less lonely. Bella sometimes felt Grippy was teasing her. She said: "It is like a friend who is constantly saying 'hey, I see you are stressed and you shouldn't be so stressed', but does nothing to help." These insights indicate how a wearable that isn't that 'smart' concerning its computational intelligence can trigger animistic connotations but may prove disappointing when the wearable does not seem to provide the support that is expected from this animistic frame.

Embedding

From the results of the analysis we also learned how Grippy became part of practical and social activities. These learnings help us to reflect on factors that influence how smart wearables become integrated parts in people's daily routines or not, and what makes them socially appropriate or inappropriate.

Situated use

Given Grippy's purpose as a therapeutic device, we found that Grippy was mostly worn in places where people anticipated stress to occur. For example, Alice would wear Grippy when she went to the office but would take it off when she was at home or went out with friends during the weekend. She explained that "I will put this thing on because I'm stressed. But I'm now going on holiday. Why should I wear it?" In addition, when Grippy is referred to as a garment, Alice considered Grippy as an outdoor gear which is "not a thing that is closely attached to your body, like the clothes or underwear that you wear and walk around at home." Similarly, Emily felt reluctant to wear Grippy at home since "when you wear something, it's most of the time when you want to protect yourself."

Social interaction

We found that Grippy could trigger participants to engage in conversations with other people but it could also lead to social awkwardness. Alice, Emily and Frank felt positive when talking about Grippy with others. Alice would even show off Grippy to her friends. Emily told about a relaxing conversation she had with her colleagues during lunch when one of her colleagues joked that "the glove [the glove-shaped version] looks like Spiderman's glove." However, Bella and Diane described how they felt embarrassed by Grippy when they felt like it exposed their emotions to others. Diane recalled an episode when she was visiting her friends. She started to feel stressed during a conversation about the graduation projects and wanted to press the button to ask Grippy to help her relax. She recalled at that moment "for some reason my [her] friends' eyes were all on my [her] hand [that wore Grippy]." She felt like that Grippy revealed her feelings to others, as if saying out loud "what you were talking about makes me uncomfortable." Emily shared an experience when Grippy started to vibrate right at the moment she ran into someone she was trying to avoid. She felt that Grippy made her feelings "noticeable" to that person, which was like "[you are] getting red in the face and… everyone could see it."

Transformation

We also gained insights about the ways in which participants learned to use Grippy to help them deal with stress. Learnings from this perspective will help us to look into the potential of Grippy to help people in behaviour change and improve their mental health.

Developing awareness

Grippy showed the potential to help participants become more aware of stress. For example, Alice commented that Grippy helped to make her stress more "explicit" which would otherwise be "a very inner and blurry thing." Bella said Grippy made her reflect on how stressed or angry she was in a particular moment so that she could "react more consciously" next time. Frank commented that Grippy was useful to help him recognize stressful moments, which "I [he] normally would not check." However, being more aware of stress might become a burden. Bella was afraid that Grippy might add more stress rather than decrease it when it made her stress more noticeable in situations that are already demanding. Diane expressed the concern that Grippy might make her more stressed when it intervened in situations where she was uncertain about whether, and to which extent, she is stressed.

Objectifying stress

We learned how Grippy could help participants gain a sense of control over stress by objectifying it. Both Caroline and Emily mentioned that Grippy provided a means to make stress more palpable by rating it through squeezing the glove. Caroline said that the interaction with the haptic interface made her stress "a measurable thing, and no longer a thing that you feel subjectively… [and thus] manageable." Even though participants were sometimes confused by the vibrational signals of Grippy, these vibrations in general provided an opportunity for participants to reflect on the causes of stress and possible actions to deal with it. Frank commented that Grippy provided "a zoom-out perspective" from which he could look at himself from an objective stance and check whether there were things that made him stressed, and possible actions to take to cope with them at the moment, for example by "stretching the body or taking a short walk." Bella said that wearing Grippy helped her to look at her feelings more objectively. On this point, she recalled how Grippy brought her back to reality when she was lost in her mind thinking about a previous unpleasant experience at work. She said Grippy made her realise how silly it was to be upset about a past experience that had no connection with what was actually happening at that moment.

Stress release

The action of squeezing was used by some participants as a way of releasing stress. For example, Alice said that the action of squeezing and feeling the vibrational feedback helped her to calm down. She mentioned how it felt similar to "stamping her feet" when she got angry, but then less noticeable. Emily also appreciated how the vibrational feedback of Grippy helped her "throw out" her negative emotions. Both Alice and Emily mentioned that the action of squeezing had become a natural thing for them to do, something that they might start to miss after they gave Grippy back. To our surprise, Bella used Grippy's function of Comforting Support as a meditation guidance in her weekly routine of meditation exercises. As she recalled, the vibration of Grippy helped her to focus on her wrist and thus find balance between her body and mind during the meditation.

6.3.2. Formgiving vocabulary and genres

How people have experienced wearing and using Grippy informed our conceptual understanding of Grippy as an *organ*, a *collaborator* and a *mentor*. In this section we provide a short recap of the definition of the genres, how it has been applied in shaping the embodiment, behaviour and interactivity of the Grippy prototype, and what we have learned about it based on the results of this study. Table 6.3 summarises our findings resulting from analysing the field study of Grippy in terms of the vocabulary in comparison to its intended ways of interaction (as shown in Table 5.1).

Organs refer to smart wearables that translate sensed signals into observable signals so as to help the wearer be more aware of the situation and able to deal with it reflexively. Grippy has been designed to *translate* sensor readings from the body into observable signals as they are occurring. Grippy does this by sending vibration signals immediately when it senses that the heart rate and number of steps have exceeded set thresholds (i.e., its *ephemerality*). The first type of signal is intended to prompt the wearer to reflect on their level of experienced stress, the second one to physically activate the wearer. Results seem to show the potential of Grippy to help people become more aware of stress. On the other hand, Grippy failed to physically activate them or remind them to do so. Participants were confused about what Grippy's signals represented and seemed to have interpreted them as stress reminders only. This also included the 'Challenge Prompt' signal described below for the *collaborator* genre. The confusion may have been the result of perceptual similarities between the signals, which we identified above as usability issues. Grippy's *reflexive* interaction has seemed to occur; participants described the interaction with the haptic interface to be intuitive and playful, which indicates a kind of interaction that is direct and does not require overthinking it.

Collaborators can engage the person in collaborative activities through their expressed intent and negotiable interactions. As a *collaborator*, Grippy has been designed to allow the wearer to deal with potential stressful situations by prompting the wearer to go on a self-training exercise or start one on their own initiative. The collaboration between Grippy and the participants did not happen as we intended. In the interview five of the six participants reported that they did not go on self-training exercises during the five days. This is partially due to the fact that Grippy was not clear in communicating its *intention* to encourage the wearer to go on a self-training exercise (i.e., again referring to the usability issues described above). Neither did they follow the *procedure* Grippy provided to guide them through a self-training exercise. Four of the six participants explicitly mentioned they did not feel the need to practise dealing with stress, nor would they break their daily routines just to follow Grippy's suggestions. In terms of Grippy being *negotiable*, these participants mentioned how they would just ignore Grippy's encouragement for a self-training exercise. The intended collaboration could furthermore be 'overridden' in the example where the comforting signal has been used by one of the participants to support her meditation sessions.

Mentors are smart wearables that have the 'wisdom' and the sensitivity to teach their wearers (mentees), and show flexibility in the support they provide by learning from previous interactions. In the Grippy prototype we have included the *co-development* as a interactive feature of Grippy, in that it stores historical data on stress and uses that data to initiate interactive behaviour (i.e., generating 'challenge prompts') and providing a means of inspection and reflection by visualising these data points on a map. Results indicate that the annotated map was barely interacted with. Participants pointed out that the annotated map did not provide information to depict particular stressful situations, but simply where they had been. It was hard for them to remember what made them stressed only by looking at the colored icons on the map. Solving this usability issue would require further design studies to add more information on historical experiences of the wearer. Finally, the inaccuracy of sensors (the heart rate sensor and GPS trackers in the phone) and the mis-reports of stress (e.g., caused by actions of squeezing when cycling) also add to the confusion about whether they were stressed or what caused their stress in these locations.

Table 6.3. Analysis of Grippy's experiences as the three genres of wearable partnerships.

Vocabulary (summary)	Does Grippy fit with the vocabulary of the genres?	Participants' perception
Organ - Translational: translating stress-related signals into other meaningful sensory modalities	The sensor data (the heart rate and steps) is translated into observable signals (vibrations).	Grippy helps increase participants' awareness of stress; Inactivity Reminder and Stress Reminder were not effectively perceived
Organ - Ephemeral: acting as an immediate response to stress levels	When Grippy senses stress levels about the threshold, it immediately gives off signals.	Participants were confused by the signals of Stress Reminder, Inactivity Reminder and Challenge Prompt which have similar intensity and durations.
Organ - Reflexive: enabling a reflexive kind of interaction	The wearer reflexively squeezes in response to the signal and the strength of squeezing is indicative of the amount of stress; there is no need to (over)think.	Interaction with the haptic interface was experienced as being intuitive and playful.
Collaborator - Intentional: being explicit about their intentions to engage people in a collaborative activity	The signals of Stress Reminder and Inactivity Reminder, and Challenge Prompt have intentional meanings ("are you doing OK?", "come on and get active" and "would you like to take up a challenge?").	Grippy's intentions to encourage the person to go on a self-training exercise were not clearly communicated to the participants.
Collaborator - Procedural: able to engage the person in dialogues to achieve their (shared) goals	Both the wearable and the wearer can start, go through, and end a self-training exercise.	The procedure provided by Grippy to guide the wearer through the self-training exercise was not followed.
Collaborator - Negotiable: The wearer can influence the intention and inner programming of actions of the smart wearable	Grippy allows for the wearer to ignore and override its intentions, and initiate the collaboration on their own.	Grippy's encouragements to make the wearer go on a self-training exercise were ignored; Grippy was used in another way (override) by one of the participants (as a meditation device).
Mentor - Co-developing: smart wearable and the wearer learn from each other over time	The annotated map can serve as a means for the wearer to gain more insights in what triggers stress and to motivate the wearer to be regularly and timely engaged in the activity of self-training.	The annotated map was barely interacted with due to the lack of situational information and mis-reports of stress.

6.4 Discussion

We learned from the participants about the different ways Grippy could help them deal with stress, how Grippy as a novel product triggered multiple understandings and interaction concerns and how the use of Grippy could be incorporated into—or could obstruct—daily activities. We also learned what functions in the design did not work at all. In particular, in this section we discuss the impact of the usability issues on the perception of the vocabulary and genres in the design. We end the discussion by reflecting on design implications of smart wearables in mental healthcare.

6.4.1 Perception of human-wearable partnerships in stress management

The results indicate that wearing Grippy on a day-to-day basis helped people to *gain awareness* of stress, but also helped people *to reflect* on the possible underlying causes. In terms of ways of managing stress, we noticed how Grippy could help people to *objectify stress* and take a *distance from it* but how Grippy was not used to take on the challenges in ways that we have intended with the design. We further noticed how Grippy was used to *release stress* by its playfulness and the enjoyable tactile experiences it provided. Overall, these findings indicate the potential of such a smart wearable in helping people to take early actions on stress. However, we acknowledge the preliminary state of the technology and the work that still needs to be done to realise this potential.

People's understanding of Grippy as a smart wearable partner involved multiple perspectives that we could unpack in relation to interaction concerns. This understanding will help us to guide its future development towards a better integrated design. Previous work being done on the design and experience of smart objects (see the work done by D'Olivo et al., 2020; Laschke et al., 2015; Rozendaal et al., 2019; Cila et al., 2017; Marenko, 2014) addresses the importance of reconciling intelligent behaviour with the meanings associated with everyday products. We continue this discussion by elaborating on the four framing perspectives we have identified before discussing issues related to their integration, i.e., *therapeutic device*, *interactive system*, *garment* and *agent*.

Understanding Grippy as a *therapeutic device* triggered associations about needing support. The extent to which such support is desired seems to have determined its use and acceptance. Although the results indicate that the wearing and use of Grippy helped some of the participants to become more aware of their stress and helped them to reflect on their possible underlying causes, we also noticed that Grippy was not well accepted by participants who consider themselves as optimistic or mentally capable of dealing with stress. Furthermore, we found how the use of Grippy could lead to embarrassment when a person believes others might see that you are using a device to help manage their stress. We also realised how the use of Grippy might feel as a burden when the wearable makes you aware of stress but does not help you to deal with it. These results draw a mixed picture with both positive and negative aspects that require further investigation when further developing Grippy as a wearable partner. Designing smart wearables as therapeutic devices therefore raises concerns about how to provide support to help people manage stress without infringing on their privacy or compromising their autonomy. Care should also be given to avoid the stigma that could be associated with such wearables. Although this study involved participants without stress disorders, also for people with stress disorders stigma is believed to be a problem (Corrigan & Watson, 2002; Hipes & Gemoets, 2019).

The understanding of Grippy as an *interactive system* raised other concerns. Usability issues for instance involved people being able to pick-up on the consistency about when, which kind of vibration signal is triggered, and the extent these signals could be distinguished from each other. It also involves issues of accuracy in reporting of stress to reduce the change of errors on reported stress levels. Furthermore, the implementation of a smartphone app as part of the interactive system was considered cumbersome because its use required additional actions and attention. These findings flag concerns in its usability although the tactile experiences Grippy produced were considered playful and enjoyable. Developing more robust interaction technology and applying embodied interaction principles could solve these problems in a redesign of Grippy (Dourish, 2004; Hummels & Overbeeke, 2010; Wensveen et al., 2004; Djajadiningrat et al., 2004; Van Campenhout et al., 2020).

As a *garment*, Grippy raised concerns about its visibility and wearability. The perceived style of Grippy—like fashion items in general—may appeal to some but not to all. Grippy had different stylistic associations as something 'cool' but also as 'manly' and 'sporty'. Reflecting on the design and people's responses to it, Grippy could have been designed with a particular style in mind, which requires decorative elements but more importantly, the miniaturisation and integration of technology in the fabrics themselves. Some of the work could be found in the domain of e-textile or smart textiles (Komolafe et al., 2021). Grippy's wearability raised issues about its convenience to wear in particular settings as people normally wear gloves for the purposes of hygiene and protection against physical injury and becoming cold. Also the electronics, including the plastic casing and the haptic interface, seemed to have compromised its usability as a glove. However, the strap-like version of Grippy, which could easily be pulled up on the wrist, did not disturb the use of the hand as much as the glove version did. These issues have been found important as they can severely block or promote daily use. Therefore, the general design principles of wearable technologies should be adhered to when designing smart wearables as partners, these issues such as washability, aesthetics and comfort (Gonçalves et al., 2018; Motti, 2020; Rotzler et al., 2021). In our research, that was beyond our scope, but it should be foregrounded when further developing Grippy as a wearable partner.

Lastly, understanding Grippy as an *agent* involved the perception of being able to communicate with it and the extent it could keep you company similar to pets or close friends. Some participants applied this animistic metaphor to make the subtle sense of companionship Grippy provided them, but it broke down when assessing if the wearable truly supported them if they felt stressed. We think that these reflections should lead to a discussion on what the right level of animism in the design of smart wearables as partners might be, such that the user does not under- or over- estimate the level of intelligence of the smart wearables (which is also discussed by Visser et al., 2016 and Looije et al., 2010).

Furthermore, integrating solutions to all these aspects into a fully integrated design is a classical design challenge. We realise that much more design and engineering efforts by an interdisciplinary team are required to bring Grippy beyond the level of a speculative probe to a standalone usable product (see also Chapter 5). Only when the design is developed to that level, it makes sense to reintroduce veterans with PTSD to test whether or not they would find this product helpful. The last point of reflection concerning integration is the danger of adopting a positivist perspective of Grippy's sensing capabilities. Dourish (2004) argues how from a *positivist* angle, context is representational and predetermined. However, as he proposed, context should be taken as "an emergent feature of the interaction" that is not separable from, but is defined by the ongoing activity in the moment (p. 23). This alternative view encourages an *interactional* perspective to design context-aware systems that value the richness of lived experiences and diverse encounters between individuals and technology. This we have fully embraced, and we would like to emphasise how attention should be paid to Grippy's dialogue and sensemaking based on the data gathered.

6.4.2 Perception of formgiving vocabulary and genres of partnerships

Summarising on the learnings of Section 6.3.2, we see how usability issues interfere with the recognizability of Grippy's prototypes in terms of the vocabulary and the genres of wearable partnerships. For organs, its signals should have a correspondence with bodily changes to work: noticing how something is signalling while you also experience pressure in the chest for instance. The triggering of false signals obviously obstruct such a correspondence. Furthermore, misinterpretation of the intentions that are expressed by the signals interferes with the smart wearable being recognized as a *collaborator*. For *collaborators* and *mentors* a correct interpretation of the signals in line with their intended meaning would lead to a shared language between the wearer and the wearables through which they can communicate with each other effectively and efficiently. On this point, the expression of Grippy's intentions is hampered by the limitations of our skin to detect detailed vibrotactile signals. After the experiment, we found out that this limitation has also been recognized as a grand challenge by other researchers (Maclean, 2008; Sonneveld & Schifferstein, 2008) who acknowledge the difficulty of enciphering semantic meanings into vibrations. Finally, the false signals undermine the *mentor*'s function of *co-developing* with the wearer, as, for that to work, signals should be trustworthy.

6.4.3 Contribution to design for mental healthcare

Our work provides insights for developing novel interventions for stress management that utilise wearable technologies. In developing such interventions, designers face the challenge of monitoring stress in everyday contexts based on different kinds of data. Unfortunately, there is no golden standard in doing so. Kusserow, Amft, and Tröster (2012) described how people experience stress in their own unique way. Situations that are stressful for one person might not be stressful for another, or even for the same person at a different time. Also, the social norms and cultural differences can influence how stress is experienced. Similar to the work done by Sanches et al. (2010), we used physiological and contextual data combined with experiential data collected through self-reports. In this way, we disambiguated the meaning of the data by asking people to make sense of it for themselves, which in itself is also a means for self-reflection. Note that, asking people to reflect on their stress should be done with care, since awareness of stress has been found to increase the level of stress (MacLean et al., 2013).

Current wearable technologies for stress management tend to inform the wearer of their condition, which is consistent with the mainstream of persuasive technologies. Note that the whole notion of persuasion, and also nudging, is ethically controversial (see e.g., Hekler et al., 2013) because of the ethical concern that any instruction of new behaviour might undermine one's autonomy (Purpura et al., 2011). This ethical concern also applies to smart wearables. With smart wearables becoming increasingly intelligent we foresee the need for approaches that allow smart wearables to help humans in ethical ways. Grippy provides a base to imagine such partners doing things on their own initiative which can be accepted but also contested. More specifically, Grippy, if not the current design, opens up discussion on how a (wearable) partner should behave to negotiate with the person in ways that suits the person and the situation. For instance, Grippy's behaviour to remind people whenever it thinks the person is stressed is not well appreciated during social conversations or encounters. Therefore, its nudging behaviour should be adjusted to a more invisible manner when it senses such situations. Furthermore, when talking about collaboration, it is important to consider the common ground in which the collaboration takes place. That is, in the case of Grippy, both Grippy and the wearer agree that they are working together to find out potentially stressful situations where the person can conduct self-training exercises to learn to cope with stress. The common ground, however, should be built on the person's ultimate goals (or motivation) which cannot, and should not, be forced upon the wearer by the wearables, like a therapeutic treatment should start after a person comes to a psychologist (which can be taken as a signal of asking for help).

Even though the current design of Grippy is not ready for people with actual needs, we see the potential to integrate smart wearables in mental healthcare. eHealth solutions, for example agent-based coaching systems, have become a valuable complementary support in the delivery of mental healthcare services (Kinderman et al., 2016; Tielman et al., 2019). Smart wearables could be designed to be applied as a tool for psychologists to help patients practice exposure therapy by themselves, extending the availability of psychotherapy outside of the clinic. This would support their recovery, decrease the workload of psychotherapists, and may lower healthcare costs.

6.5 Conclusion

This chapter presents a field study of Grippy, a smart wearable designed to encourage people to actively seek out and learn to cope with stress in everyday contexts. As a design, Grippy is informed by the concept of wearables as partners and the vocabulary of shaping expressiveness of such partners. Using the Objects with Intent framework, we interpreted how Grippy as a wearable partner could help people raise awareness of stress, objectify stress, and find ways to release it (*transformation*). We also learned how Grippy could trigger multiple understandings and interaction concerns, for instance, as a garment, an interactive system, a therapeutic device and an agent (*framing*), and how the mixed perception of Grippy and technical limitations could affect its embedding in people's everyday life (*embedding*). These insights further led us to consider factors that influenced participants' acceptance of Grippy. In particular, Grippy as a therapeutic device might trigger social stigma that are associated with mental vulnerability and lack of autonomy. As an interactive system, critical issues were raised about how Grippy could involve the wearer in effective and efficient interaction regarding the challenge of using vibrotactile signals to communicate semantic meanings. The identity of Grippy as a garment brought us to considerations on basic requirements of a smart wearable being a garment, such as social visibility and wearability. Such considerations provide new insights to address the classic challenge of integrating a design's purpose, aesthetics, usability, and perceived agency into a unified experience in the context of designing smart wearables.

Furthermore, this field study has provided first-hand experiences that led us insights into which functions of Grippy would warrant the perception of Grippy as an *organ*, a *collaborator* and to some extent a *mentor*. In summary, Grippy could be interpreted as an *organ* that can enable the wearer to report and release stress reflexively. However, as a *collaborator* its intentions were not clearly communicated. Neither were participants willing to break their daily routines to follow Grippy's suggestion and guidance. We conclude that this mismatch between our design intentions and the actual experiences of the participants, is mainly caused by usability issues. For example, the intended meaning of communicative signals were unclear to the wearer, and false signals were caused by the inaccuracy of sensors and unintentional triggering of activations by the wearer. Furthermore, due to a lack of situational information and false signals, the annotated map did not contribute to the perception of Grippy as a *mentor*. These problems were major barriers for wearers to perceive Grippy as a wearable partner. Nonetheless, Grippy proved to be a valuable research tool.

CHAPTER 7

General discussion

This chapter reflects on the findings of this research project as a whole. First, it discusses how a Research-through-Design (RtD) process was followed and how that influenced our research questions while we were going through the process to answer them. Insights are discussed in terms of the alignment of research and design activities, the use of prototypes as research tools, the multiple roles taken on by the PhD researcher, and how—in retrospect—reflexivity is important to help identify changes that occur during the process in light of the complexities encountered in trying to achieve an ambitious research aim. The discussion continues with reflecting on the conceptual exploration of smart wearables as partners through multiple perspectives, i.e., therapeutic relationships (used for inspiration), partnership qualities and genres (that emerged from the work) and the Objects with Intent framework (used as an analytical lens). Then a critical reflection is given on the limitations of the work regarding our ultimate goal in creating smart wearables for veterans with chronic PTSD. This chapter also discusses ethical concerns that emerged during the conduct of the studies. A general conclusion is presented at the end of this chapter.

7.1 Research-through-Design process

This PhD project made use of a RtD process because of its aim to investigate smart wearables as partners as a design proposition. Building towards this proposition requires organising research and design activities in tandem over time to explore its potential social value, the engineering challenges involved. As part of the process we formulated new theories, provided partial answers to the research questions and reformulated new research questions, as is presented in Chapter 1. In the remainder of this section we elaborate how the undertaken research and design activities relate to each other. Finally, we reflect on the design knowledge outcomes of the RtD process at each successive step.

7.1.1 Alignment of research and design activities

The project started with a *design vision* that has been *substantiated* by the experiences of veterans with PTSD who might benefit from it. This vision on smart wearables as partners has been informed by intelligent agents, emerging discussions in HCI on human-computer partnerships and symbiosis, and how wearables bear unique characteristics as collaborative partners. Then, a qualitative study was conducted with veterans with chronic PTSD to learn about their experiences of stress and how smart wearables could be of value for them (RQ1). The interpretation of the design vision in relation to the empirical data gained, led to the *construction of a conceptual framework.*

The next step in the research was motivated by the need to better understand how partnerships can be *expressed* through smart wearables (RQ2). Taking the research question that the conceptual framework brought forth as a starting point, design students were invited to explore the embodiment of smart wearables in mockups used as 'props', which they then enacted and reflected upon. The outcomes of the students' work was then analysed according to the framework by Vallgårda (2014) on formgiving practice of interaction design, which allowed partnership qualities to be analysed on their expressiveness in detail. The discussion that took place within the research team led to *construction of a design vocabulary* that describes the partnerships across three genres. In this case, *design activities were the focus of the investigation itself rather than a starting point for inquiry as in the previous step*.

The third step in the project was motivated by the question of how to technically *realise* smart wearables as partners, specified by the conceptual framework. At this step too, *research and design activities coexisted simultaneously*. Different sensors were applied and integrated in a garment and a tangible self-reporting interface (*the squeezing bar*). The decision was made to work with an Arduino-based sensor system, because commercially available wearable devices (with sensors and computation embedded in them) are technically blackboxed and difficult to work with in new configurations, although they have increased performance/accuracy. It however turned out quite difficult to technically obtain good data from these sensors and to arrive at a conclusion about the level of stress a person experiences. Engaging with making also led to the idea of using the gesture of squeezing as an interaction mechanism for self-reporting on stress.

Based on the previous learnings, an integrated prototype of a smart glove, named *Grippy*, was made: a smart wearable to encourage people to seek out potential stressful situations and learn to cope with stress by means of stress exposure training. In this step, the lessons learned from the previous steps in the process (the conceptual framework, the three partnership genres and 'squeezing' interaction technique) were *applied in an integrated prototype* with the aim to be *deployed in the field as a speculative probe*. In addition, the vocabulary of the three genres was used in a retrospective reflection on realisation of the prototypes of Grippy. Thus, the design activity was combined with theoretical outputs of the previous study to reach particular expectations about how a research prototype will be experienced.

The last part of the research involved deploying Grippy in the field to understand the experience of a wearable partner when worn and interacted with during the day (RQ4). Six university students and employees were invited to wear Grippy for five successive days and to share their experiences by means of interviews. The OwI's Framework by Rozendaal et al. (2019) was used as an analytical lens to interpret the interview results. Their framework has been constructed to understand things as collaborative partners concerning the meanings they elicit, the interactions they afford within particular contexts of use, and the transformation they bring forth. The application of the framework provided deepened insights into multiple interpretation- and interaction concerns triggered by different identities of Grippy perceived by the wearers and how the use of Grippy could be incorporated into–or obstruct–the wearers' daily activities. Furthermore, we analysed to which extent Grippy has been experienced to be an *organ*, a *collaborator* and a *mentor* by referring to the formgiving vocabulary (Chapter 3). These results made us realise that usability issues are major obstacles for smart wearables to be perceived as partners in everyday contexts.

7.1.2. Prototypes as research tools

During the research project, multiple prototypes have been created that served different research purposes. Prototypes are embodied or materialised design concepts, ranging from low-fidelity mock-ups to computational systems, that could help designers to "traverse a design space" or embody theoretical hypotheses (Lim et al., 2008; Wensveen & Matthew, 2014). In this section it is elaborated how prototypes have been part of the research including using prototypes as *props* in codesign sessions to tell stories, using prototypes to research *technical functioning and integration* and deploying prototypes in the field as *speculative probes* to understand use and experience in everyday contexts. Figure 7.1 shows the three uses of prototypes as research tools during this project.

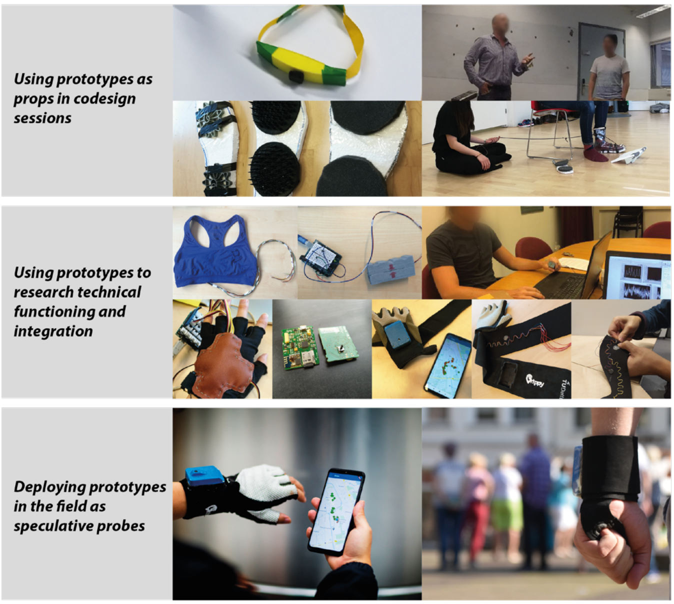


Figure 7.1 Three uses of the prototypes for research purposes in this thesis.

Prototypes can be viewed as *props* for people to share their visions about solutions to their problems. These props, defined in design research as tangible elements used in storytelling where low-fidelity artefacts are made to help people to enact fictional use scenarios and elaborate the subjective experiences they want to elicit with a design (Brandt & Grunnet, 2000; Howard et al., 2002). This role of prototypes can be related to the artefacts made from *generative toolkits* in codesign or participatory design, consisting of materials such as images, stickers, and objects, to help people envision the applications of technologies that do not yet exist (Sanders & Stappers, 2014). This use of prototypes as props have further been addressed in role-playing (Svanaes & Seland, 2004), experience prototyping (Buchenau & Suri, 2000), and somaesthetic design (Jung & Ståhl, 2018).

In Chapter 2, two veterans with chronic PTSD and one of their spouses were provided with tinkering materials to make mock-ups with the assistance of design students. The made mock-ups were then used in *storytelling* about how these designs could help them overcome stressful situations. In Chapter 3, the mock-ups made by design students were used as props in *enactments* showing how interactions with smart wearables could unfold. These codesign sessions were different in that interpretation of the prototypes made by veterans with PTSD focused on understanding their underlying *needs* and *concerns* while the prototypes made by design students were used to identify aspects of their *expression.*

Prototypes have also been made to explore the *functionality* and *integration of sensing and actuating technologies*. The research value of these prototypes is reflected in how the making of them unpacked the complexity of the technologies to achieve the experiential qualities and functions inspired by the conceptual assumptions. According to Stappers and Giaccardi (2017), designing reveals new possibilities and complexities offered by the technologies. This value of prototyping is exemplified by Chapter 4 which presents an attempt of integrating physiological sensors in a garment and comparing it with a tangible self-reporting interface in sensing stress induced in the lab. Technical and experiential aspects of the prototype were explored including placement of the sensors, the algorithms and use experiences of the tangible interface. In Chapter 5, substantial technical effort was also put into the making of Grippy in a multidisciplinary engineering team that included experts on software engineering, electronic (PCB) design and textiles/garments. Looking back, this has been quite a challenge given complexities in system integration and reaching a quality of finish in the prototype.

Prototypes have also served as *speculative probes* that enabled investigation into people's experiences of using a technology in their daily contexts. Wensveen and Matthews (2014) describe how prototypes used as a means of inquiry involves deploying prototypes in the field to analyse their use and consequences. Grippy is *speculative* in the sense of it being a proposal of a wearable partner rather than being the end-product of one. This speculative nature involves asking participants to engage with the prototype as a provisional object in a process of co-discovery to "understand social reality and explore designerly possibilities at the same time" (Halse et al., 2010, p. 37). Additionally, Grippy is a *probe* deployed in the field to learn about the effects it produces without the researcher being present. Coined by Gaver et al. in 1999, designed artefacts as *cultural probes*—inspirational materials delivered to people's homes, used in small exercises to communicate about their daily experiences and sent back to the researchers upon completion—enable a remote way of understanding local cultures. As another kind of probe, Odom et al. (2016) explored using prototypes "to be lived with and experienced in an everyday fashion over time" (p. 2551). They point out four qualities of importance to investigate situated use and experience through the use of research artefacts. We would like to highlight two of them as being relevant for this thesis. One, the importance of such artefacts to have a quality of *finish* in their look and feel, and two, their ability to function *independently*. With Grippy being deployed as a probe, we observed how problems for both these concerns (and in particular issues of wearability and instability of its functioning) created a barrier for participants to use it throughout the day. Hereby limiting the insights gained about how partnerships with Grippy could form in the long-term.

To summarise, the various uses of prototypes across studies allowed for the *scaffolding* of an initial vision of a concept to possible means of expression and embodying this in a speculative probe to investigate the experience of such a concept in real life. As pointed out by Stappers (2013), the act of making prototypes can be taken as an act of confronting technology, theory and phenomena which promotes the generation of new ideas and knowledge. Prototyping helped us, as a first step, to get closer to the central issues that deserve attention when conceptualising and realising smart wearables as partners but (until this point) has been less useful to validate its application in stress management.

7.1.3. Roles of the PhD researcher

During this project I (as the PhD researcher) needed to adopt different roles. As a *designer*, I have been involved in the making of prototypes while as a *researcher,* I have set up experiments and interpreted insights from results of the studies. As a *facilitator*, I helped others to engage in research and manage an engineering process of an interdisciplinary team. The distinct responsibilities and skills of these roles are elaborated below as well as a discussion about the combination and tensions existing between these roles.

My role of a designer is mostly reflected in the work of Chapter 5 where I elaborately reflect on the making process of Grippy. My role of a designer can be further divided into (1) working *conceptually* which involves proposing a design rationale and articulating its details, (2) working *aesthetically* to sketch out possible forms of the glove and give form to physical prototypes of the gloves using textiles, and (3) the *engineering* effort to integrate electronic components (connecting the sensors and actuators to the Arduino board) and to embed the electronics on the textiles (assisted by experts from the particular domains). Engaging in this PhD project as a designer from these aspects has equipped me with familiarity with the digital and physical materials, and crafting skills to integrate them into a design. Challenges were encountered in dealing with the different mindsets of a designer, for example, the conceptual and aesthetic ideas might be down-scaled or compromised due to limitations of the existing technologies. This is especially reflected in the design of Grippy: although a plastic casing was taken into account in the sketching of the concept, the size of the casing could only be determined at the engineering stage when the electronic components to be accommodated inside were selected and tested.

My role as a researcher is reflected in application of qualitative research methods (e.g., observation, interview, and interpretation of the qualitative data). This role required me to pay attention to theoretical insights emerging from the process and translating this into generalizable design knowledge. A challenge faced by this role of a researcher is how to make use of the (qualitative) research methods, which derive insights from the participants' experiences of the past, to match the aim of the PhD project that aims for a possible future (i.e., designing smart wearables as partners). This required me to be careful in making distinctions between the *vision* that motivated the research, the *empirical data* gathered about the participants' experiences, behaviours or creative explorations, and the *interpretation* of this data in terms of how this informs the vision or not.

My role as a facilitator is reflected in Chapter 2, 3 and 5 where I organised and hosted codesign sessions and workshops, and managed the technical development of the Grippy prototype. Specifically, two types of activities were undertaken. First, this role involved providing design tools and assistance to the participants to help them reflect on their own experiences and designs. For instance, by facilitating them to elaborate their thoughts and feelings about particular stressful situations and how they might respond to it. Second, my role as the facilitator is to manage the engineers to realise the design requirements, as illustrated by the work of Chapter 5. For example, I learned how to use state-machine diagrams as communication tools to help the software engineer and the electronic engineers to understand the complex functions of Grippy and realise such functions by means of algorithms.

However, *the boundaries between these roles were blurred*. For instance, my role as a researcher and designer involved balancing different mindsets and skills, and finding the balance between theory and practical application. My role as facilitator and researcher mixed when I needed to coordinate codesign sessions while also making observations and taking notes. Facilitating the workshop required me to keep track of time, this was at odds with my role as a researcher to focus on the thinking processes and creativity shown by the participants. My role of designer and facilitator blended while crafting the embodiment meanwhile facilitating conversations between engineers about system integration. The role of a facilitator of the engineering team drove me to make compromises about what could be made given the limits of the available technologies, the budget, and the availability of the other team members.

7.1.4. Learnings about reflexivity

In retrospect, I learned about how this PhD project can be understood as a *reflexive practice* that required paying attention to the ambition and its goals and framing based on intermediate research outcomes. Dewey (1933) defined reflexive practice as an action that involves "active, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it and the further consequences to which it leads" (p. 9). Such reflexivity, which includes constant considerations on the process and outcomes of the actions, explains a typical reasoning process of RtD which "favours a constant realignment of the construction of artefacts, based on trial and error, to better tackle complex design problems" (Godin & Zahedi, 2014, p. 6). Schön (1983) identified two types of reflection in performing the reflexive practice, namely reflection 'in' action (the kind of reflection emerging during the creative activities) and 'on' action (the reflection that is consciously performed after the action having been taken). Both kinds of reflections discussed by Schön (1983), resulted in reconsidering the research questions emerging from the work based on the ambition of the project, yet in hindsight, did not capture the research journey as a whole.

Figure 7.2 shows a schematic representation of how the research question started to deviate from the initial ambition, as the complexity of designing smart wearables that help veterans with chronic PTSD manage their stress, presented itself. Krogh and Koskinen (2020) describe how in RtD, design researchers are informed by small and unnoticeable changes that occasionally, and sometimes inevitably, make them drift away from "initial perceptions of challenges and objectives" (p. 5). In this thesis, the first pivoting occurred when asking a formgiving-related research question about how partnerships can be expressed (RQ2). Design students, instead of veterans with PTSD, were involved because they are trained with specific sensitivities and represent a designer perspective to address the research question. Stress was addressed as daily hassles experienced by people in general that worked as the backdrop of their design enactments. However, this might lead to the cost of losing a connection with veterans as our target group. Then, in parallel, an engineering oriented activity was initiated driven by the question to what extent smart wearables can actually sense stress and engage in dialogue with people wearing them (RQ3). This step in the research involved conducting stress inducement experiments with students wearing and interacting with the prototype (the garment and the *squeezing bar*) in the lab, for which involving veterans was not deemed ethical given the preliminary status of the technology and that participating in the experiment might worsen their condition. Thus, insights gained from this study did not directly hold for veterans with PTSD either. The question about how such partnerships (with the Grippy prototype) may be experienced in daily life (RQ4) required us to focus on testable participants (university students and employees) too, given the same ethical considerations as mentioned above. From above, it could be seen that most pivoting adjustments derived from the decision of involving non-PTSD participants in the studies and reframing stress as everyday experience that applies to people in general, instead of a chronic condition. To come back to a 'full circle' future research is suggested to reintroduce and connect with veterans with chronic PTSD and their caregivers to assess the applicability of the design on both a technical and experiential level, and identify research gaps leading to new research. On the other hand, these intermediate deviations from the original ambition do not deny the contribution of the thesis which provides relevant knowledge on "smart wearables as partners" and "design for stress management". This knowledge should be taken as useful and necessary intermediate steps before we move forward to our actual target users, i.e., veterans with PTSD.

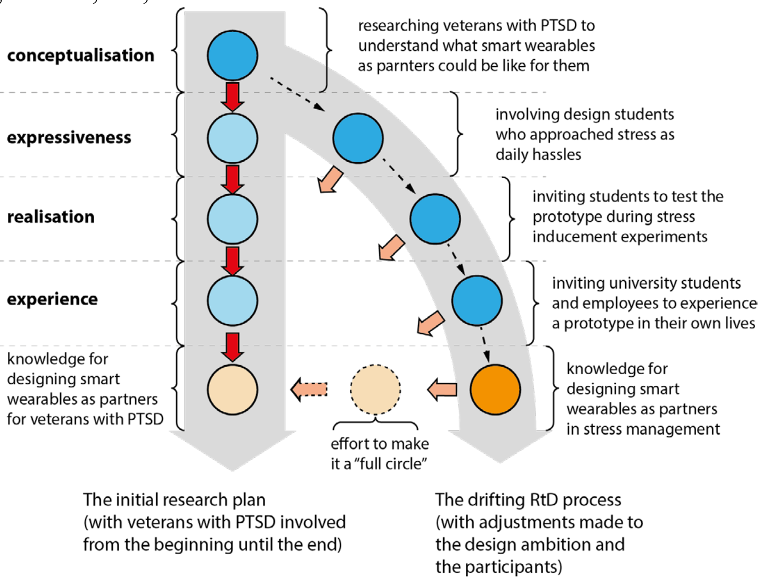


Figure 7.2 Comparison between the initial research plan which veterans with chronic PTSD are the focus and are involved in each step of the research, versus the actual 'drifting' process where veterans with chronic PTSD are the focus but have only been involved at the start of the research after which Non-PTSD participants (university students and employees) have been participating.

7.2 Learnings on designing human-wearable partnerships

The collective work presented in this thesis is centred around the insights about how partnerships with smart wearables can be *conceptualised*, *expressed*, *realised* and *experienced*. This section elaborates on the different perspectives that have been taken on board to shed light on the understanding and design of smart wearables as partners. It is then discussed how the key insights gained from these perspectives are related by flagging connections and disconnections. Also, the technical complexity of realising smart wearables is discussed.

7.2.1 Multiple perspectives

The work presented in this thesis takes on board four perspectives to shed light on the understanding and design of smart wearables as partners. In Chapter 2, inspiration was taken from *therapeutic partnerships* that people might have with other humans and animals in the practice of stress management. In Chapter 2, three *partnership qualities*, i.e. trustworthiness, respectfulness and discreetness, were identified by reflecting on veterans' stories of how they deal with stress and how they envision smart wearables could help them. Then in Chapter 3, three *partnership genres* have been identified (*organ*, *collaborator* and *mentor*) that provide a description about the wearable partners' embodiment, temporality and ways of engaging people in interaction. In Chapter 6, the *Objects with Intent* framework was used as an analytical lens to understand how Grippy was experienced as a collaborative partner in everyday situations and activities. These perspectives have been presented and discussed separately within each chapter but we compare them here as a posteriori reflection on the work.

Therapeutic partnerships and their qualities

Therapeutic partnerships with humans or animals could provide some further insights on the understanding of *trustworthiness*, *respectfulness* and *discreteness* of smart wearables as embodied agents. First**,** trustworthiness of humans and animals is perceived differently from that of computational agents. Before explaining their differences, it should be noted that trust and trustworthiness are two different concepts. Trust is a "a psychological state", which is assumed to be held by humans in interpersonal relationships, that refers to "the intention to accept vulnerability based upon positive expectations of the intentions or behaviour of another'' (Rousseau et al., 1998, p. 395). Trustworthiness, as a property that has been used to describe not only humans but also animals and things, is the characteristic that inspires positive expectations for being dependable for "doing what one [the other party] is trusted to do" (Hardin, 2002, p. 28). The trustworthiness of computational agents for instance is associated with their reliability and transparency when assisting humans in teamwork (Ferreira Gomes Centeio Jorge et al., 2021). Trust violation and trust repair are discussed in (Baker et al., 2018; Tolmeijer et al., 2020). Trustworthiness “begets” trust, but does not necessarily guarantee it; see (Hardin, 2002) and (Misztal, 2013) for a social and psychological understanding of trust and trustworthiness.

Interesting for our work in creating artificial partners is the trustworthiness of animals as partners for human activity. In particular, we looked at service dogs. Service dogs for blind people have proven their trustworthiness through their capabilities to assist their owners to conduct various daily routines, like guiding their owners to travel in public transport (Rickly et al., 2021). Furthermore, service dogs have been introduced as partners for veterans with PTSD (Houtert et al., 2018). Trustworthiness of these service dogs is based on their ability to emotionally bond with their owners through their sensitivity to human familiarity and emotions (Thompkins et al., 2021). Understanding the trustworthiness of service dogs and the trust that their owners have in them provides a perspective to analyse the trustworthiness of computational agents, for example in navigation systems for blind people (Bai et al., 2018), and in emotionally expressive and adaptive robots that engage children in play (Tielman et al., 2014). As for the intelligent agents for emotional support, it is interesting to note that there might be a mismatch between the trust placed in them and their trustworthiness, see e.g., (Tielman et al., 2014). People in general hold “presumptuous estimations” about what robots are capable of due to their seemingly intelligent appearance and influence from media such as movies and books that overhype the capabilities of robots (Baker et al., 2018, pp. 8-9). Trustworthiness of (or trust placed in) intelligent agents is context dependent and should be viewed by balancing the benefits and risks afforded by the interaction (Baker et al., 2018).

Second, reflection on respectful behaviour of humans might provide inspiration on how to design respectful (wearable) computational agents. Respectful behaviour can be understood as a subset of social behaviour that shows positive feelings (e.g., a sense of honour and admiration) by “expressing care, concern or consideration for people’s needs or feelings” (*Merriam Webster; Cambridge Dictionary*). Building on the notion of respect, effort of designing respectful agents (or AI) can be found which seem to focus on concern for human’s moral needs, such as autonomy competencies (Formosa, 2021), data privacy (Siau & Wang, 2020), and being treated justly (Robert et al., 2020). This research should be taken into account when designing respectful smart wearables as well.

Finally, the relationship should be discreet, by which we mean the quality of discreteness as being “careful not to cause embarrassment or attract too much attention, especially by keeping something secret” (*Cambridge Dictionary*). Discreet behaviour of humans can be interpreted by how the person behaves appropriately given the particular social and cultural situations. Taking this into consideration, a smart wearable can be discreet by being socially appropriate in terms of appearance and behaviour. In this sense, a bulky and loud wearable device might not be considered as being discreet.

Partnership qualities and genres

Another point of discussion is how the resulting *partnership qualities* could deepen the understanding of *partnership genres*, and vice versa. The three genres provide an account to describe how trustworthiness of smart wearables could be built in alignment to people's interpretation/expectation of "what they are *trusted* to do". Smart wearables as organs, which are considered as less intelligent computer agents, might gain trustworthiness by their stability and predictability in making translations of physiological signals. Trustworthiness of smart wearables as collaborators, which are trusted for their abilities to negotiate with wearers and provide procedural guidance, should be based on how they could communicate efficiently and provide useful information for the ongoing collaborative activity. As for mentors, their trustworthiness could be perceived for how well they could adapt to one's needs and preferences through learning from the interaction. *Respectfulness* of the three genres could be understood by how they satisfy people's needs in different aspects. For organs, their respectfulness might be reflected in their concern for some basic needs for wearables such as 'not being forced on the bodily level' (non-intrusiveness) and 'not being interrupted'. Collaborators can be considered *respectful* when they allow the wearer to freely decide whether to follow, ignore or go against the actions suggested by the wearable—that is, respect for 'individual autonomy'. Mentors are respectful by being able to keep the person in the loop while learning from the interaction—that is, respect for people's need of being informed of their personal situation. Thinking about the *discreetness* of organs brings forth reasoning about how smart wearables draw attention from others given how they appear, while for collaborators this might refer more strongly to the social appropriateness of their behaviour. For example, making noise during a musical recital, thus embarrassing the wearer. Such embarrassments could be prevented if the smart wearable has proper understanding of social situations. The discreetness of mentors might be expressed through knowing when and how to act properly according to their understanding of the person and situation. Different from collaborators whose behaviour is predetermined, the discreteness of mentors could be gained from learning from the person.

Objects with Intent framework

What did we learn about *partnership genres* by analysing people's experiences of using Grippy with the *OwI framework*? The analysis of Grippy as an interactive system highlighted how the squeezing interaction was found to be playful, informing the organ genre about how reflexive interaction can be enjoyable. The confusion people experienced in distinguishing between Grippy's vibration signals when interacting with it demonstrated the importance of clear communication when wearables express intent and provide procedural guidance, which are important for the collaborator genre. What we have learned about Grippy as a therapeutic device is how motivation is critical to realise the potential of smart wearables as collaborators, and mentors especially, because the co-development they intend to achieve requires a person to invest in a learning process. Analysing Grippy's situated use and social interaction showed how the wearability and visibility of a wearable can seriously hinder using it and therefore is of great importance for all three genres. Lastly, the analysis of the extent Grippy may have changed people's behaviours and experiences, informed the genres by showing how wearing Grippy helps to remain aware of stress and how the squeezing of Grippy could release stress momentarily. This confirms our expectation that using smart wearables as organs helps people to deal with stress reflexively. However, some participants indicated that they did not feel the need for support in dealing with stress, and therefore used Grippy less to take on challenges, actively try to calm down, or learn from previous interactions. This indicates the importance for people to agree on, and commit to, the objective of the partnership the wearable makes possible. On the other hand, the fact that the wearer can ignore these signals without being unduly bothered by the signals, is important as the wearable can be worn also at times when some of its functions are not needed.

7.2.2 Realisation - Technical complexity

Insights were gained about the complexity of using physiological sensors and tangible self-reporting interfaces to collect stress-related data. Despite the increasing technological applications, difficulties to accurately sense stress in real life situations have been commonly mentioned by researchers (Choi et al., 2011; Guribye et al., 2016; Kusserow et al., 2012; Lowe & ÓLaighin, 2014). In Chapter 4, we indeed found it difficult to use physiological sensors to provide direct reference to one's experienced stress. Body movements can obstruct the connection between the sensors and the skin which leads to noisy data and this seems inevitable when the sensors are worn in natural environments. Although the use of better-quality sensors and advanced algorithms might improve the quality of data, the challenge still exists regarding associating this data with one's subjective experience of stress.

Challenges were also encountered in using tactile actuation as ways of communicating. In the design of Grippy, we used a vibration motor located on the back of the wrist. Difficulties were encountered in this manner of communication. The varied vibrations produced by the vibration motor could not be well perceived by the wearers. Participants of the field study of Grippy found it difficult to distinguish the three different vibrational signals since they were similar in terms of the duration and intensity. More effort in pre-selecting the vibration motor, self-testing and tailoring the algorithms in the lab would have helped to make the vibrational signals more distinguishable. However, even with these signals distinguishable, the challenge of using vibrational signals to convey abstract information, like "go forward and take up the challenge" in the case of Grippy (Challenge Prompt), might still exist since our skins are not as capable of deciphering vibrational signals into semantic meanings as our eyes to symbolic graphics or as our ears to acoustic signals. This challenge of linking haptic signals to semantic/semiotic meanings has also been recognized by other researchers (Maclean, 2008, p. 169; Sonneveld & Schifferstein, 2008). One solution to overcome this is to train the users to memorise the semantic meanings (predefined by designers) that are attached to particular vibrational signals, although this might mean more learning effort from the users before they could make the semiotic connection naturally.

Technical challenges of integrating electronics into wearable systems were also encountered. First, such challenges include balancing the functionality and wearability of the wearables while integrating electronics. For example, the physiological sensors (heart rate sensor, temperature sensor and skin conductance sensor) are required to be closely attached to the skin. For this reason, we embedded the sensors in a stretchy garment (Chapter 4). However, some participants experienced the garment as being too tight. The technical compromise on wearability is also reflected in the plastic casing placed on top of the smart glove (Grippy). Despite the engineering effort to scale down the size of the electronics to be accommodated inside, for example, by using printed circuit board (PCB), the plastic casing was found to be cumbersome when using the hand. To design collaborative behaviour of a wearable partner, the work on co-active design for human-robot teamwork is relevant (Johnson et al., 2014a; Johnson et al., 2014b). Following this co-active design method, the *teamwork behaviour* of the smart wearable and its wearer should be observable, predictable, and to some extent directable for each other in a way that fosters collaboration and does not necessarily distract each other. In particular, the physical design of the robot is altered to enable human team members to take over control of some parts of the robot's actuators. Combining co-active design with co-design workshops is a way of ensuring that the insights of the human-robot interaction (HRI) community are taken into the design of the smart wearable that is to function as a partner. A second concern is the wear and tear of the prototypes. The movement of the human body and friction between the electronics and fabrics could cause physical damage to the wires stitched on the fabrics and connection between the electronic components. To alleviate this impact, in the design of Grippy we stitched the flexible wires on the fabrics in a zig-zag pattern so that the glove can be stretched without breaking the connection of the wires. Still, the robustness of the prototypes remains a big challenge given the various potential physical damages and is to be further tested since they were only tested either temporally in the lab or for a few days in the wild. Third, maintenance of the prototype is another aspect that requires further attention. A Lithium-ion battery was added to make the smart glove function continuously during the day, but this also required the wearer to charge it on a daily basis. The glove is not washable, making it difficult to wear for too long and to pass it on to another person for hygienic reasons. It should, however, be noted that all these challenges (sensor signal distortion, actuator performance, interconnections and washability) are challenges for all current wearables and many research teams are working on it. Future prototypes can therefore be expected to benefit from new developments in the field.

7.2.3 Application in stress management

During the research project, the need arose to involve university students and employees without chronic stress disorders in the research. This created a gap between these participants and veterans with chronic PTSD as our original target group. Below, we elaborate on the reasons for involving these groups and critically discuss how the relatively milder and more temporary kinds of stress they dealt with confounds the applicability of the outcomes of the research.

Veterans with chronic PTSD, for whom we intend to develop smart wearables as partners, experience stress on a daily basis which they need to deal with as a long-term, or even lifetime condition (Friedman, 2015, p. 6). Mundane daily activities such as taking the bus or shopping can trigger severe stress reactions because traumatic memories may be triggered by these everyday situations, and in case of war veterans, oftentimes include memories of events that happened during missions (Friedman, 2015; van der Wal et al., 2021). These *chronic*, *intrusive* and potentially *overpowering* aspects of PTSD make veterans with PTSD a socially relevant case for whom smart wearables as partners could be a valuable aid. Three veterans of war and their spouses were consulted at the start of this project to understand how they cope with stress in daily life and how smart wearables can be of use. However, in the studies that followed, veterans with PTSD have not been involved. We elaborate on the reasons why, and how the kinds of stress these participants groups have dealt with are different from chronic PTSD.

The speculative design workshop described in Chapter 3 was performed with students to better understand how partnerships could be expressed through smart wearables. Design students rather than veterans with chronic PTSD were involved because of the speculative nature of the work and the design sensitivities it required. The stress explored and imagined by the students should be described as "daily hassles stress" that provided the backdrop for their design exercises. Daily stressors of this type are different from the stress people with PTSD experience.

First, daily hassle stress originates from particular situations and when resolved lowers the stress. This is fundamentally different from the stress veterans with PTSD experiences during flashbacks where there is a disconnect with cognitions and the events, which actually are taking place.

Students were also involved in testing the sensors and self-reporting interaction mechanisms in the lab. Described in Chapter 4, university students rather than veterans were invited to participate given the experimental approach used to induce stress. Involving veterans in this study was deemed unethical. Following a classical stress inducement procedure based on Choi et al. (2012), Plarre et al. (2011) and Müller et al. (2016), experimental stimuli were created to induce different levels of stress which takes the forms of a fast reading exercise, a mental arithmetic exercise and sudden appearance of a scary image. The impact of the stress inducements were assessed based on data collected from physiological sensors, a tangible self-reporting interface and subjective feedback of the participants. Here stress is about challenges that do not arise from earlier traumatic experiences. Furthermore, stress that is induced in lab environments might be experienced and dealt with differently, compared to stress that may arise in everyday situations.

The experience assessment of the Grippy prototype reported on in Chapter 6 was performed with university students and employees. They were invited rather than veterans with chronic PTSD because of the preliminary state of the concept and prototype. Focusing on stress as it occurs and is experienced being situated in people's real life brings it closer to the lived realities of veterans with chronic PTSD. Still, this falls into the range of 'daily hassles' that are generally mild and short-term stressors, and that people are able to deal with without psychological support. Evidently, the road towards smart wearables that are applicable and readily helpful for veterans with PTSD is still long.

7.4 Ethical concerns

In this section, we reflect on other ethical concerns that presented themselves during this project. These include considerations on the risk of compromising individual autonomy, emotional privacy, and the potential negative psychological impact of the smart wearables on stress.

Designing technological support to help people deal with stress can undermine a person's autonomy to deal with stress themselves. Persuasive technologies have been critiqued to be *dehumanising* when designers adopt the intent to fix "basic human flaws" (Purpura et al., 2011, p. 429). The ethical dilemma of helping people to change their behaviour without undermining their free will is especially tricky in the context of mental healthcare. Research points out that people gain psychological resilience, i.e., the ability to mentally or emotionally cope with a crisis, from dealing with disadvantageous situations in life (De Terte & Stephens, 2014; Rutter, 1999; Rutter et al., 1998; Schofield, 2001). This raises the question how smart wearables can be designed to help people manage stress by empowering them in the process of gaining resilience. The work presented in this thesis suggests how this could be done by challenging a person out of his/her comfort zone—which a person can decide to take on, or not—to practise coping with stress. And even more crucially, how to involve a person in what the goals of this learning will be.

Another issue that arose is how a person's privacy needs to be safeguarded when interacting with smart wearables that can sense stress, allow them to respond to by expressing emotions, and store this as data. Generally, we learned how our participants talked about how smart wearables should act in socially appropriate ways, and should not attract attention from others (i.e., discreetness). Results of Grippy showed how participants felt embarrassed when they thought that Grippy's actuation, or the way they could respond to it, might have exposed their emotions to others. Furthermore, the storage of emotion-related personal data by smart wearables is another issue for designers to consider. Although this has not been the focus of research in this thesis, it is clear that people should give their consent to what extent personal data is collected and shared with others.

Another aspect that designers should pay attention to is the potential negative impact on stress caused by smart wearables themselves. Research by MacLean et al. (2013) showed that being aware of stress itself can lead to increased stress. The findings from the field study of Grippy, which showed how wearing a smart wearable could cause stress by prompting a person to focus on it or be perceived as a symbol of stress, seems to confirm this effect. Furthermore, participants mentioned their frustration about usability issues, which could also lead to stress. Design strategies from positive design (Desmet & Pohlmeyer, 2013) may help reduce or mitigate these negative impacts by emphasising how a design can evoke positive emotions or moods. The playful experience of squeezing Grippy, as reported by the participants in Chapter 6, shed some light on what a stress-releasing as well as positive interaction with smart wearables could be like.

7.5 Conclusion

Arriving at a conclusion about the contributions of this PhD project requires a critical reflection on whether the concept of smart wearables as partners has been understood and what we have learned about its application for veterans with chronic PTSD. This work has made a humble yet notable contribution to the academic design community by having made an initial step in unpacking 'smart wearables as partners' concerning their qualities, multiple forms of expression, technical challenges, and experiences. An important point of learning on design research methodology has been about understanding Research-through-Design as a reflexive practice where research questions emerged (or were adjusted) while engaging a complex phenomenon and new challenges presented themselves.

Combining these insights with the open challenges we described in Section 7.2 it becomes clear that creating a smart wearable partner for stress management for PTSD veterans is still a dot on the horizon. Before we can create a design that might work, we have to find solutions for the wearable to have a clear and meaningful dialogue with the wearer at appropriate moments, and to make sure the wearable is unobtrusive to wear. Unobtrusiveness here means that the wearable is not noticeable by people surrounding the wearer, while on the other hand, it should be easily noticeable and not too demanding for the wearer. The unobtrusiveness requires the wearable to be much smaller, and more integrated with normal daily wearables, and that the actuators need to give unobtrusive signals (e.g., vibrations) to the wearer. The complication of having sensors that are sensitive enough and can read through the interference of the bodily movements of the wearer is a major challenge. Despite the accuracy of the sensor and disturbance of the body movements, the challenge still exists to make any direct interpretation about one's experience of stress based on bio-sensed data. A solution to this is to use this information as a way to involve the wearer in a dialogue. Some initial effort in this direction has been made in this thesis (e.g., using the heart rate as a reminder for self-reporting). However, more is to be explored about whether such a dialogue is appreciated by the wearer and how it could help the person to deal with stress. Thus, more work is required in many disciplines to provide the fundamental components needed to create smart wearables as partners for veterans who suffer from PTSD as a chronic condition.

Based on these considerations, we conclude that currently it would still take more than one PhD project to develop a smart wearable partner for veterans who suffer from chronic PTSD.

Executive summary

This thesis is motivated by the vision of designing smart wearables as *partners* for veterans with chronic posttraumatic stress disorder (PTSD). Everyday objects are becoming 'smarter' with the integration of computational and electronic technologies. It is now possible to start thinking of these objects as 'intelligent agents' that can form collaborative relationships to help us with issues that were hitherto impossible. Smart wearables show the potential to be designed as "partners" that are able to continuously monitor bodily and behavioural signals, to involve the human body as part of the interaction, and help the person whenever possible and in ways other products cannot. People with chronic PTSD, who face the challenge of constantly dealing with various everyday stressful situations, provide an interesting case to explore the concept of such partners.

PTSD is a type of stress disorder that develops in people who experience traumatic events. A typical group of people who have PTSD are post-deployment veterans who suffer from symptoms such as intrusive memories, fierce physical arousal and behavioural reactions that are triggered by everyday situations which remind them of traumatic experiences in war zones. Such symptoms can last for a long term, and sometimes even lifetime. These *chronic*, *intrusive* and potentially *overwhelming* aspects of dealing with stress make veterans with PTSD a relevant case in which smart wearables as partners could be a valuable aid.

Despite therapeutic interventions that are provided in clinics under the guidance of therapists, not many applications are found that could help people with PTSD to deal with stress in everyday contexts. Smartphone and smartwatch apps exist that can help these people to deal with stress outside clinics. Interaction with these apps takes place on small-sized screens, requiring withdrawal from current activities and full attention from the wearer. What is lacking are applications that can engage the person in interaction without unnecessarily interrupting everyday activities. Smart wearables (taking forms of clothing, garments and accessories) designed as partners have potential in the idea of having embedded sensors to measure current stress levels and gain situational awareness, and having other means of interacting with the wearer (e.g., haptic interaction on different locations of the body). Commercially available wearable devices (such as Fitbit and Apple Watch) are technically blackboxed and difficult to work with in new configurations. To be able to explore the potential of smart wearables, the decision was made to work with Arduino-based sensor systems. Thus, we set off on an exploration of the technologies to realise the design of smart wearables as partners, and experimenting with actual interactions with them.

This thesis is set up with research questions aiming to explore and gain insights into how partnerships with smart wearables can be *conceptualised*, *expressed*, *realised* and *experienced*.

Chapter 2 aims to answer the question of *what partnerships with smart wearables could be like for veterans dealing with chronic PTSD (conceptualization)*. A qualitative study was conducted to get an impression of how veterans with chronic PTSD experience and cope with stress in daily life. Following this, a co-design workshop was organised with veterans to learn how they themselves envision smart wearables in the future. Results of the study substantiate a conceptual framework that highlights the key aspects to consider when designing smart wearables as partners, including aggregation of multiple sources of data to understand the person and the situation, providing appropriate types of support, and the experiential qualities that are considered relevant when relating to a smart wearable as a partner. This work helps deepen our understanding of the design vision from a potential gap informed by the theories and current technological applications to a conceptual model that is supported by empirical evidence of the target users.

Chapter 3 is driven by the question of *how partnerships can be expressed through smart wearables (expression)*. Design students were asked to participate in a workshop, in which they imagined smart wearables that help people manage stress in different stressful situations. Interpretation of the speculative designs crafted and enacted by design students led to three genres of wearable partnerships, namely *organs*, *collaborators* and *mentors,* which can be described in terms of the physical and temporal form of wearables, and ways of affording particular kinds of interaction. Note that in this study stress was approached as a ‘backdrop’ of the students’ design exploration. The focus is on the various expressions manifested by smart wearables in the interaction that might apply across different scenarios and groups of people. The vocabulary of the three genres could help designers to gain sensitivity and tactfulness in how the digital and physical materials could be organised in meaningful ways to contribute to the partnerships with the smart wearables.

To answer the question of *how smart wearables as partners can be realised (realisation),* Chapter 4 and 5 present the process of making two prototypes, a garment and a smart glove. The making of the garment involves integrating different sensors in the garment to collect physiological data from the human body and to enable the wearer to report self-perceived stress using tangible interfaces taking the form of a ‘squeezing bar’. Through testing the garment in the lab, we learned how difficult it is to technically obtain good data from these sensors and realise the value of using the self-reporting tool to understand the person’s experienced stress when it occurs. In Chapter 5, we describe the making of a smart glove, named *Grippy*, as a partner to encourage people to seek out potential stressful situations and learn to cope with stress by means of stress exposure training. The design of Grippy is informed by the concept of the three partnership genres, and further utilisation of the ‘squeezing’ interaction technique. These two chapters help us to gain further understanding of the concept of wearable partnerships on the level of realisation regarding the complexities of integrating electronics and computational intelligence in wearables that suit the contexts of the lab and real life.

In Chapter 6, we learn about *how people experience wearing and interacting with a smart wearable during the day (experience)* by deploying Grippy in the field as a speculative probe. University students and employees were asked to wear and use the smart glove for five days successively. We learned how Grippy triggered interaction concerns and multiple understandings, which shed light onto the ways in which partnerships with smart wearables may form and the kinds of support they may provide. However, we also learned that Grippy is still very far from an actual partner that can help the wearer to learn to deal with stress. Major obstacles are the current state of the art in wearable sensors, actuators, and the difficulty of designing effective haptic communicative signals. Starting with non-PTSD participants in this study was a modest, but essential intermediary step towards our ultimate goal of providing support to veterans with chronic PTSD who need to be approached with extra care and attention.

Chapter 7 presents a general discussion on the work of this thesis and a research agenda looking forward to future studies. In particular, we reflect on how the RtD process unfolded itself concerning the alignment of research and design activities, how prototypes have been used as research tools and how the PhD researcher needed to combine different roles during this process. We discuss how—in retrospect—a "drifting" research process took place with changes and adjustments made to the aims and setup of the studies along the way. Then, the previous chapters are critically reviewed concerning the extent to which they deepen the understanding of designing human-wearable partnerships and what is yet to be delivered on our initial ambition to help veterans with chronic PTSD to deal with stress. This chapter also discusses some of the ethical concerns that presented themselves during this project. It ends with a general conclusion of the thesis.

In summary, this thesis has made an initial step in unpacking 'smart wearables as partners' as a vision worth further explorations in the fields of design and human-computer interaction. In retrospect, this vision still is a dot on the horizon and it will take more than one PhD project to achieve. Still, our work provides a valuable aid for designers and researchers to better sort out challenges and opportunities when attempting to address the topic in the future.

Samenvatting

(Translation by Marian Loth and Boudewijn Boon)

De aanleiding voor dit proefschrift is de visie van het ontwerpen van 'slimme wearables' als *partners* voor veteranen met een posttraumatisch stress syndroom (PTSS). Alledaagse objecten worden steeds 'slimmer' door de integratie van computertechnologie en elektronica. Het is nu mogelijk om deze objecten te gaan zien als 'intelligente actoren' die kunnen samenwerken met mensen en mensen kunnen helpen met problemen, wat eerder niet mogelijk was. Slimme wearables hebben de potentie om te worden ontworpen als "partners" die signalen van het lichaam en het gedrag kunnen monitoren, het menselijk lichaam kunnen betrekken als deel van de interactie, en mensen kunnen helpen op manieren die andere producten niet kunnen bewerkstelligen. Mensen met chronische PTSS, die constant met verschillende stressvolle situaties moeten omgaan, vormen een interessante casus om 'slimme wearables' als partners te verkennen.

PTSS is een stress stoornis dat zich ontwikkelt bij mensen die traumatische gebeurtenissen hebben meegemaakt. Een typische groep mensen die PTSS hebben, zijn post-actieve veteranen die lijden aan symptomen zoals indringende herinneringen, krachtige fysieke opwinding, en gedragingen die worden getriggerd door alledaagse situaties die hun herinneren aan traumatische ervaringen in oorlogsgebieden. Zulke symptomen kunnen lang aanhouden, soms zelfs levenslang. Deze *chronische*, *indringende*, en potentieel *overweldigende* aspecten van het omgaan met stress, maken veteranen met PTSS een relevante casus waar slimme wearables als partners een waardevol hulpmiddel kunnen zijn.

Ondanks therapeutische interventies die aangeboden worden door klinieken onder de begeleiding van therapeuten, zijn er maar weinig applicaties die mensen met PTSS kunnen helpen bij het omgaan met stress in alledaagse situaties. Smartphone en smartwatch applicaties maken gebruik van kleine schermen die de volle aandacht van de gebruiker vragen, waardoor de aandacht van de gebruiker onttrokken wordt van zijn of haar huidige activiteit. Wat ontbreekt zijn applicaties die mensen in een interactie betrekken zonder alledaagse activiteiten te onderbreken. Slimme wearables, in de vorm van kledingstukken en accessoires, die ontworpen zijn als partners, hebben door hun ingebedde sensoren de potentie om het actuele stressniveau te meten en om bewust te zijn van de situatie. Ze hebben ook andere middelen om te interacteren met de drager; denk bijvoorbeeld aan haptische interactie op verschillende locaties van het lichaam. Draagbare apparaten op de markt, zoals de Fitbit en Apple Watch, zijn technologisch een 'black box' en zijn moeilijk om mee te werken in nieuwe configuraties. Om de potentie van slimme wearables te verkennen, is de keuze gemaakt om met sensor systemen te werken op basis van Arduino. Hiermee zijn we technologieën gaan verkennen om slimme wearables als partners te ontwerpen, en om te experimenteren met daadwerkelijke interacties die mensen ermee hebben.

Dit proefschrift behandelt onderzoeksvragen om inzichten te vergaren over hoe partnerschappen met slimme wearables *geconceptualiseerd*, *uitgedrukt*, *gerealiseerd* en *beleefd* kunnen worden.

Hoofdstuk 2 tracht een antwoord te bieden op de vraag *hoe partnerschappen eruit zouden kunnen zien tussen slimme wearables en veteranen die te maken hebben met chronische PTSS (conceptualisatie)*. Een kwalitatieve studie is uitgevoerd om een indruk te krijgen van hoe veteranen met chronische PTSS stress ervaren en hier mee omgaan in het dagelijks leven. Vervolgens is er een co-design workshop georganiseerd met veteranen om te kijken welke voorstelling zij zich maken bij slimme wearables in de toekomst. Resultaten van de studie onderbouwen een conceptueel raamwerk dat belangrijke aspecten benadrukt om te overwegen wanneer je slimme wearables als partners ontwerpt; voorbeelden van deze aspecten zijn de aggregatie van meerdere databronnen om de persoon en situatie te begrijpen, het aanbieden van geschikte vormen van ondersteuning en de belevingskwaliteiten die relevant zijn wanneer iemand zich verhoudt tot een slimme wearable als partner. Deze resultaten helpen ons begrip van de ontwerpvisie te verdiepen door de stap te maken van een hiaat, geïnformeerd door theorieën en huidige technologische toepassingen, naar een conceptueel model dat wordt ondersteund door empirisch bewijs van de beoogde gebruiker.

Hoofdstuk 3 draait om de vraag *hoe partnerschappen uitgedrukt kunnen worden door middel van slimme wearables (expressie)*. Ontwerpstudenten werden gevraagd deel te nemen aan een workshop, waarin ze slimme wearables bedachten die mensen helpen om met hun stress om te gaan in verschillende stressvolle situaties. Het interpreteren van deze speculatieve ontwerpen, waarvan de interacties ook uitgespeeld werden door studenten, leidde tot drie genres van partnerschappen, namelijk *organen*, *samenwerkers,* en *mentoren*. Deze genres kunnen beschreven worden aan de hand van de fysieke en temporele vorm van de wearables, en de manieren waarop ze specifieke interacties mogelijk maken. Merk op dat in deze studie stress werd benaderd als achtergrond voor de exploratie door de studenten. De nadruk lag op de verschillende uitdrukkingen die zich door wearables manifesteerden in de interactie, welke van toepassing kunnen zijn in verschillende scenario’s en groepen mensen. Het vocabulaire van de drie genres zou ontwerpers kunnen helpen om gevoeligheid en tact te krijgen in hoe digitale en fysieke materialen op betekenisvolle manieren georganiseerd kunnen worden om bij te dragen aan de partnerschappen met de slimme wearables.

Om antwoord te geven op de vraag *hoe slimme wearables als partners gerealiseerd kunnen worden (realisatie)*, presenteren Hoofdstuk 4 en 5 het maakproces van twee prototypes: een kledingstuk en een slimme handschoen. Om het kledingstuk te maken, zijn verschillende sensoren geïntegreerd om fysiologische data van het menselijk lichaam te verzamelen en om de drager het mogelijk te maken om zelf waargenomen stress te rapporteren, doormiddel van het gebruik van tastbare interfaces in de vorm van een 'knijpstaaf'. Door het kledingstuk te testen in het lab hebben we geleerd hoe technisch uitdagend het is om goede data te verkrijgen van de sensoren. Ook werden we ons bewust van de waarde van de zelfrapportagetool om de ervaren stress te begrijpen wanneer het plaatsvindt. In hoofdstuk 5 beschrijven we het maakproces van een slimme handschoen, genaamd *Grippy*, welke als partner mensen aanmoedigt om op zoek te gaan naar mogelijk stressvolle situaties en om te leren omgaan met stress door middel van 'stress exposure training'. Het ontwerp van Grippy is gevormd op basis van de drie genres van partnerschappen en maakt gebruik van de 'knijp' interactie techniek. Deze twee hoofdstukken helpen ons om het concept van draagbare partnerschappen te begrijpen op het niveau van realisatie met betrekking tot de complexiteiten van het integreren van elektronica en computer intelligentie in wearables die passen de context van het lab en het echte leven.

In Hoofdstuk 6 leren we meer over *hoe mensen het dragen van, en interacteren met, een slimme wearable beleven gedurende de dag (beleving)* door het inzetten van Grippy als 'speculative probe'. Studenten en medewerkers van een universiteit werden gevraagd om de slimme handschoen te dragen en te gebruiken gedurende een periode van vijf achtereenvolgende dagen. We hebben geleerd hoe Grippy interactie zorgen en meerdere begrippen teweegbracht, wat licht wierp op de manieren waarop partnerschappen met slimme wearables vorm krijgen en de vormen van ondersteuning die ze kunnen bieden. We hebben echter ook geleerd dat Grippy nog verre van een daadwerkelijke partner is die de drager kan helpen om met stress om te leren gaan. Grote obstakels zijn de state of the art in technologie, met name op het gebied van draagbare sensoren en actuatoren, en de moeilijkheid van het ontwerpen van effectieve haptische communicatieve signalen. Door deze studie uit te voeren met participanten zonder PTSS nemen we een bescheiden, maar essentiële, tussenstap in de richting van ons uiteindelijke doel om ondersteuning te bieden aan veteranen met chronische PTSS, welke met extra zorg en aandacht benaderd dienen te worden.

Hoofdstuk 7 presenteert een algemene discussie over het werk in dit proefschrift en een onderzoeksagenda voor toekomstige studies. We reflecteren met name op hoe het proces van ontwerpend onderzoeken ('research through design') zich ontvouwde met betrekking tot het afstemmen van onderzoeks- en ontwerpactiviteiten, hoe prototypes gebruikt zijn als tools voor onderzoek, en hoe de promovendus verschillende rollen moest combineren gedurende dit proces. We bespreken hoe – achteraf gezien – een 'drifting' (NL: 'afdrijvend') onderzoeksproces plaatsvond, waarin gaandeweg veranderingen en aanpassingen werden gemaakt in de doelen en opzet van de studies. Vervolgens werpen we een kritische blik op voorgaande hoofdstukken met betrekking tot de mate waarin ze het begrip verdiepen van het ontwerpen van mens-wearable partnerschappen en wat er nog moet worden gerealiseerd voor onze aanvankelijke ambitie om veteranen met PTSS te helpen om te gaan met stress. Het hoofdstuk bespreekt ook enkele ethische zorgen die zich aandienden gedurende dit project. Het hoofdstuk sluit af met een algemene conclusie van het proefschrift.

Samengevat heeft dit proefschrift een eerste stap gezet in het ontrafelen van ‘slimme wearables als partners’ als een visie die het waard is om verder te verkennen op het gebied van ontwerpen en mens-computer interactie. Achteraf gezien is deze visie nog steeds een stip op de horizon en zal er meer nodig zijn dan een enkel promotieproject om deze te bereiken. Toch levert ons werk een waardevol hulpmiddel voor ontwerpers en onderzoekers om uitdagingen aan te gaan en oplossingen te zoeken wanneer zij in de toekomst dit onderwerp aan willen pakken.

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Appendices

Appendix 1: Interview script for the study with veterans with PTSD

Interview [NAME] - DD/MM/YY

Part 1: Self-introduction
Videos Day 1 & 2: 'Self-portrait' & 'A day in the life'

Focus: Who are our participants? What is their life situation?

Time: 10 minutes

Given questions:
Day 1:
Self-introduction
a favorite hobby
favorite music
family situation

Day 2:
Daily routines
Morning or evening rituals
Working situations
House/neighborhood environment

Further Questions
When did you start this hobby?
How often do you do this?
How do you feel when doing this?
How would you describe yourself (in one word) if you are to meet a new friend?
How would you behave differently in front of your family? Why?

NOTES

Part 2: Everyday life objects as potential resources (for future design)
Videos Day 3: "Your stuff"

Focus: How do they view these objects as "presence" in their daily life? What qualities make them valuable?

Time: 15 minutes

Given Questions:
Wearing stuff
Clothes or accessories
Things you are attached to
Items you often use
Why you are wearing or using something
What is the story behind a special property?
Have you got it or purchased at a special moment?

NOTES

1

Further Questions:
What is the situations where you would use it?
How do you feel when wearing it (or taking it along with you)?
Can you show us where you would store it when not using it?
What makes you feel like to keep it (them) with you often?

Part 3: stressful moments & existing/ reliant resources

Videos Day 4: Difficult situations

Focus: Which problems do they face in daily life? Which psychological & social resources help them deal?

Time: 20 minutes

Given Questions:
Tell us about the situations that are stressful to you.
Can you picture these situations?
Can you explain why these situations are difficult?
How can you make it clear to others what you sometimes experience?

Further Questions:
How do you feel in such a situation?
What are the core challenges in it?
How do you recognize the situations?
How do you cope with these situations?
What resources/strategies do you rely on?
Where did you gain these resources?

NOTES

Part 4: envision a future design

Videos Day 5: possible solutions

Focus: How do they envision a future design by themselves? Which things do they envision themselves to be an appropriate resource?

Time: 30 minutes

Given Questions:
How could a new product help you?
What features should this product have?
Can you imagine how this product could work?
What solutions would not work for you at all?

NOTES

2

Further Questions:
With regards to the previously mentioned "your stuff", can you think of a new design based on those by adding new features?
(What are these features and how will it work?)
If you are asked to describe it as a person, what kind of person(nality) will you relate it to?

Part 5: social support
Videos Day 6: People around you

Focus: How does the social network support the participants (especially in a stressful situation)?

Time: 20 minutes

Given Questions:
Introduce a number of people who are important to you.
Can you ask them to tell you something?
Can you picture a joint activity (for example, with family, friends or colleagues)

Further Questions:
Will you turn to these people (specifically) when you are in a difficult situation (as you mentioned before)? Or do they come to you?
What are the difficulties or obstacles in communicating with them on these issues?
How can a design help in such a situation?

<u>NOTES</u>

Part 6: Debriefing
Videos Day 7: People around you

Focus: no more doubts; appreciate contribution; reflect on methodologies

Time: 10 minutes

Further Questions:
How do you like the way of making your own Vlog in the past week?
Is there anything you want to add with regard to the experience of the past week?
What are the obstacles and advantages?
How do you suggest us to improve?

<u>NOTES</u>

3

Appendix 2: Setup of the co-design workshop with design students

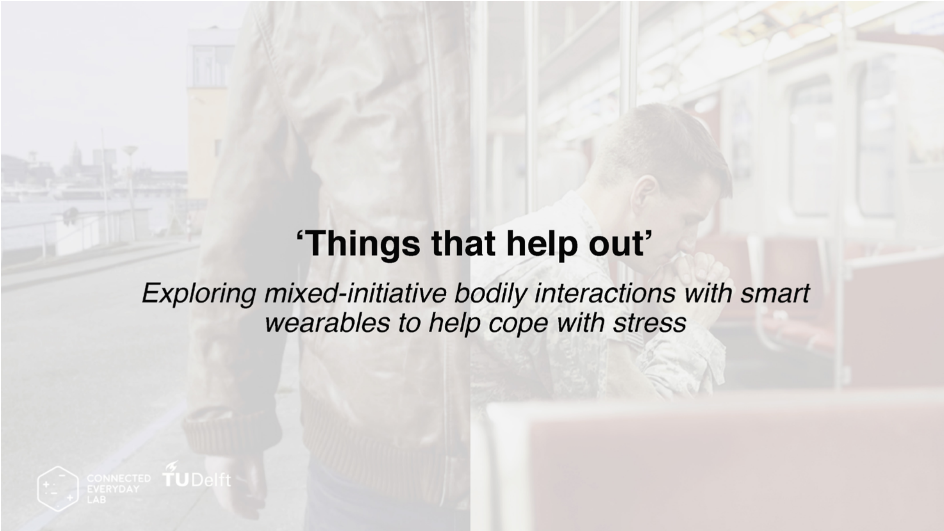

Figure A1. Topic of the workshop.

Figure A2. Program of the workshop.

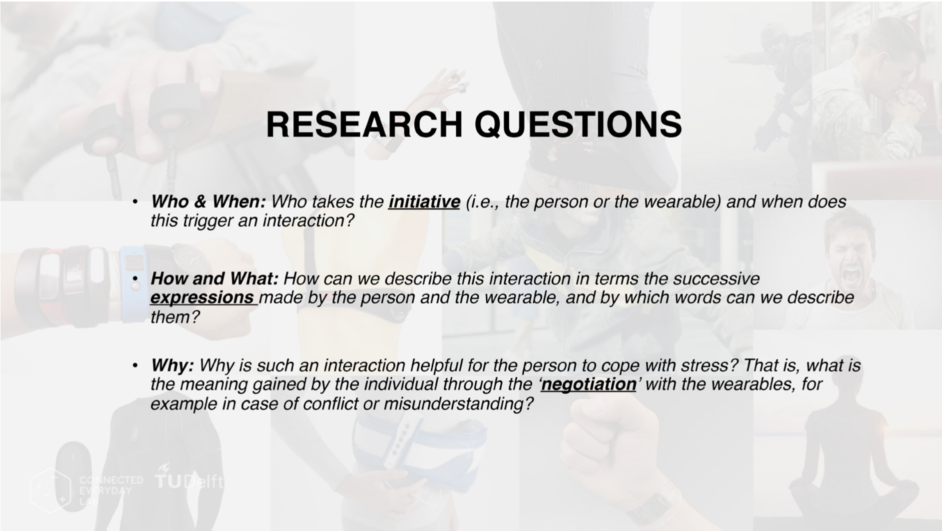

Figure A3. Introduction of the research questions.

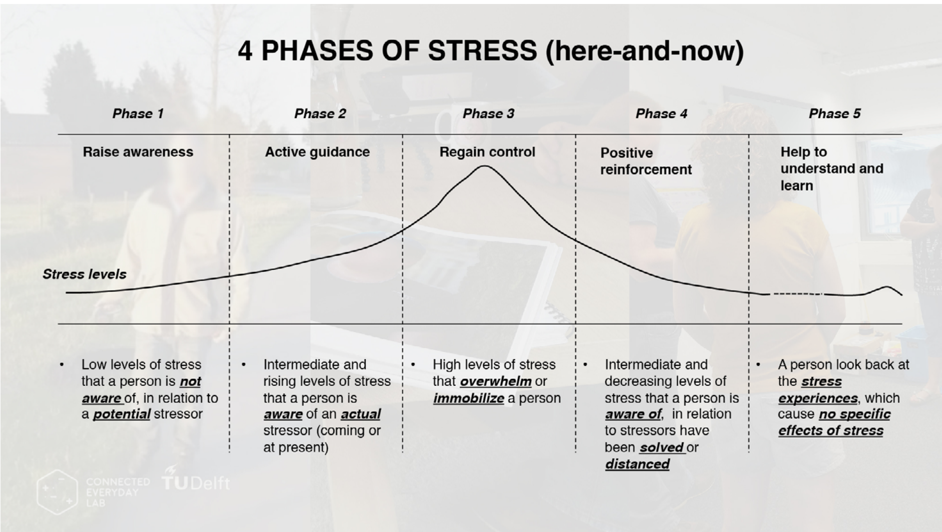

Figure A4. Four phases of coping with stress (hypothesis).

Appendix 3: Script of the Interview for the field study of Grippy

In this interview we would like to ask you about the experiences of using the glove in general and will follow up with some specific questions. The interview has four main parts: Part 1 focuses on understanding the experiences of Grippy in general. Part 2 focuses on Grippy's usability and identification of critical usage situations. Part 3 focuses on peoples understanding of the Grippy as a partner in stress management, and Part 4 ends with reflection on the conduct of the study and your suggestions for future studies.

Part I: Overall Experience

General Impression (10 mins)

- What was it like for you having used Grippy these past couple of days?
- In general, how often did you wear the glove and what did you do with it?
- In general, how often did you check the map?
- In general, did it help you in some way?

Character (5 mins)

- How would you describe Grippy? What kind of a product is it to you?
- Could you further describe Grippy in terms of the following aspects?
    - Its appearance (what it looks and feels like?) *follow-up about the glove and app separately
    - Its behaviour (What it does and how it behaves?) * follow-up about the glove and app separately
- How would you describe the personality of Grippy (as if you would describe it as a person)?

Wearing the glove (10 mins)

- How did you experience wearing the glove? *follow-up on issues of wearability and comfort
- o Where did you put your phone when wearing the glove?
- Please mention anything else that comes to your mind in terms of wearing it.

Part II: Usability and Critical Use Situations

Usability Issues (10 mins)

- How did you experience using Grippy?
- Could you further describe the use of Grippy in terms of the following

features?
- ◆ o Grippy's functions * follow-up on the 4 functions separately, i.e.
  - ▪ § bio-sensing and self-reporting of stress (Glove)
  - ▪ § inactivity reminder (Glove)
  - ▪ § prompt for challenges (Glove)
  - ▪ § the annotated map on the phone (App)
- ◆ o Grippy's signals and visual communication * follow-up on the glove and app separately
  - ▪ § Glove: could you describe the signals you felt? Could you tell the differences between these signals? * follow-up on meaning and affective experience
  - ▪ § App: how do you like the icons, colours and symbols of the app?
- ◆ o Grippy's controls * follow-up on the glove and app separately
  - ▪ § Glove: How do you like the use of the glove in terms of squeezing, button, and strap and unstrap (etc.)?
  - ▪ § App: How do you like the use / interaction of the App? Anything that makes it easier or harder to control it?

- Please mention anything else that comes to your mind in terms of using it.

Critical Use Situations (10 mins)

- Could you recall usage situations that you considered particularly useful or annoying? * identify 2 useful and 2 annoying situations
- Could you further describe these situations according to the following aspects?
  - ◆ o The activity you were engaged in that moment *follow-up in terms of how Grippy integrated or disturbed this activity
  - ◆ o The physical setting (indoor/outdoor, heat, cold)
  - ◆ o The social setting *follow-up in how other people were involved: witnessing, participating, etc.?

Part III: Reflection on the Glove as Being a Partner in Stress Management

How the glove made you aware of your bodily feelings of stress (10 mins)

- In which situation(s) did the glove draw your attention to (or made you feel aware of) feelings of stress? * Identify 2 episodes
  - ◆ o Can you describe this specific episode?
  - ◆ o How did the glove do to make you aware? *This question might be repeated when participants were reflecting on other episodes.
  - ◆ o What effect did this have on you? How did you respond (react) to it?

*This question might be repeated in other episodes.

The glove helped you to deal with stress during specific moments (10 mins)

- Can you share an episode of how it helped you to deal with your stress? * Identify 2 episodes
- Did you go for a challenge by yourself (without any trigger from the glove)?
  - o What did you do?
  - o Did it work for you?
  - o What was your motivation then?
  - o Can you share with me an episode?
- When you receive a signal reminding you that you are nearby a stressful location, how did you respond?
  - o In which situation would you accept the challenge?
  - o What did you do then?
  - o Did it work for you?
  - o Can you share with me an episode?
  - o In which situation would you ignore it?
- Please mention anything else that comes to your mind in terms of using it.

The way the glove helped you understand your own ways of feeling and dealing with stress over time (10 mins)

- Did the use of Grippy help you get more insights into your levels of stress and how you deal with it?
- After wearing it for one week, did you experience any difference compared with when you wore it for the first time?
- Did you learn any lessons or new skills in dealing with stress (with the help of the glove)?
  - o What are they?
  - o How did the glove help you to learn this?

Part IV: Debriefing

Any issue the participant might still have or wants to share (5 mins)

- Is there anything interesting or important that has not been talked about?
- Do you have any comments or advice on the conduct of the study?

Thanks for your participation, and we will keep you updated about the progress of the study in the future.

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About the author

Xueliang Li was born in Xingtai (Village of Xixianxian), Hebei Province, China in 1990. After obtaining his bachelor's degree in Industrial Design from Hebei University of Technology (Tianjin, China) and master's degree in Design from Jiangnan University (Wuxi, China), Xueliang continues his study in pursuit of a PhD degree at the faculty of Industrial Design Engineering, Delft University of Technology (Netherlands).

Xueliang's PhD focuses on designing smart wearables to help people, in particular veterans with post-traumatic stress disorder (PTSD), to deal with stress in everyday contexts. During his PhD, he works with an interdisciplinary team across domains of computer science, electronic engineering, mental healthcare, fashion design, and interaction design. Based on his PhD research, he has extended his interest in the topics of design for mental health and subjective wellbeing, and designing everyday objects as intelligent agents that provide care and companionship. Trained as a designer and having grown to be a design researcher, Xueliang has adopted a research-through-design approach as a way to pursue research goals through design activities and initiate collaboration with people from different disciplines.

In June 2022 Xueliang will join the School of Design, Southern University of Science and Technology (Shenzhen, China) as a tenure-track assistant professor.

List of publications

Li, X. (Sean), Rozendaal, M. C., Jansen, K., Jonker, C., & Vermetten, E. (2021). Things that help out: designing smart wearables as partners in stress management. *AI & SOCIETY*, *36*(1), 251–261. https://doi.org/10.1007/s00146-020-01003-0

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