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

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Smart wearables are increasingly used to help people deal with stress. Still, a less explored area of research in this field concerns the partnerships that smart wearables can take on when engaging people in stress-coping activities. To facilitate further understanding of the human-wearable partnerships, we designed Grippy, a smart wearable system composed of a physical glove and a smartphone application to help the wearer actively explore and cope with stress in daily situations. We introduced Grippy, as a speculative probe, to six participants (four master students and two university employees) who wore 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 regarding how Grippy could fit into people's stress-coping activities across different daily contexts and what kinds of partnerships with the smart wearable were perceived by the participants. In addition, 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 in the context of stress management and the usability issues that might hinder the expression and acceptance of smart wearables designed as partners. We end the discussion by reflecting on the implications of smart wearables as partners in mental healthcare.

Keywords **–** Interaction Design, Stress, Smart Wearables, Human-agent Interaction.

Relevance to Design Practice – This paper presents a field study of a smart wearable system to facilitate further understanding of human-wearable partnerships in the context of stress management. Results of this study are helpful for designers who aim to design wearable technologies to promote people's mental health on a daily basis.

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Introduction

The increased capabilities of wearables to make sense of measured bodily and behavioral signals corresponding to stress and to communicate this back to a person opens up opportunities for developing smart wearables as partners in stress management. The characteristics of smart wearables—being continuously present as a garment, involving the human body as part of the dialogue, providing support whenever possible, and collecting data in ways that stationary products cannot—make smart wearables a potential partner that can provide a valuable aid to people in dealing with stress on a daily basis. The idea of designing smart wearables as partners falls into a broader movement in HCI (human-computer interaction) that imposes critical thinking on our relationships with contemporary computational things, which are becoming increasingly intelligent, interconnected with humans and each other, and intertwined with our daily lives. Our relations with such computational things contain the qualities of relationships: interactions with them can take the form of negotiations to maintain a balance of agency and control, which may shift over time. This also requires an understanding of the emotional, social, economic, and ethical involvements such relationships can imply (Wiltse, 2020). In the following parts of this section, we explain how we approach the topic of designing smart wearables as partners by means of a conceptual framework and a *form-giving* vocabulary that is intended to explore partnerships with smart wearables as a kind of developing relationship. This sets the theoretical basis for the design of a smart wearable prototype that is tested in a field study.

Designing Smart Wearables as Partners

Our interest in exploring smart wearables as partners originates from the motivation to help veterans with PTSD who experience stress as a chronic and potentially overwhelming condition. The aspect that stress hinders them in daily life makes them an interesting target group to investigate the concept of smart

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wearables as partners. In a previous study (Li et al., 2021), we proposed a conceptual framework (Figure 1) for designing smart wearables 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 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. The study presented in this paper builds further on this work by exploring the dynamic interactions between smart wearables as partners and their wearers and how such partnerships can be shaped by employing different types of design materials, as will be introduced below.

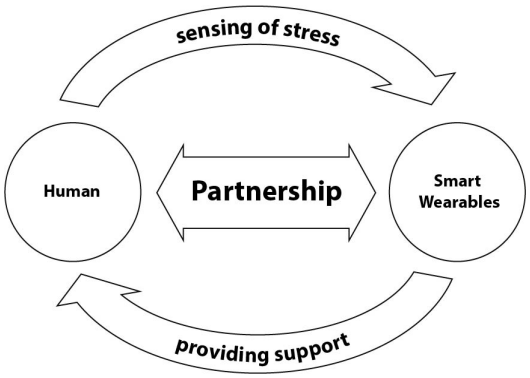

Figure 1. A framework for designing smart wearables as partners (Li et al., 2021).

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Marco C. Rozendaal is an associate professor of Interaction Design at Delft University of Technology. With a background in interactive media, design, and engineering, his research straddles multiple disciplines and combines practical, critical, and methodological perspectives. His current work explores the design of new interaction styles and paradigms engendered by Artificial Intelligence (AI).

Eric Vermetten is a psychiatrist and professor of Psychiatry at Leiden University Medical Center and Adjunct Professor at New York University School of Medicine. Up to 2021, he was appointed as Strategic Advisor (COL) of Research at Military Mental Health of Ministry of Defense. He has a track record in working with veterans with PTSD. His focus is on medical/biological as well as psychiatric aspects of complex psychotrauma in the military as well as civilian populations.

Kaspar Jansen is a professor of Emerging Materials at the Faculty of Industrial Design Engineering. His initial research focused on polymers and polymer processing and later shifted towards material modeling of molding compounds in microelectronics. His current research interests involve electronic textiles, Smart Materials, shape-morphing materials, and electroluminescence.

Catholijn Jonker is a professor of Interactive Intelligence at the Faculty of Electrical Engineering, Mathematics, and Computer Science of the Delft University of Technology. With a value-sensitive approach, she works towards intelligent agents that can interact with their users in value-conflicting situations when also meta-values no longer solve the situation. In TU Delft, she works with an interdisciplinary team to create synergy between humans and technology by understanding, shaping, and using fundamentals of intelligence and interaction.

Towards a Vocabulary to Shape Smart Wearables as Partners

In another study (Li, 2022), we proposed a form-giving vocabulary for designing smart wearables as partners. This vocabulary is composed of three genres of human-wearable partnerships, namely *organs, collaborators*, and *mentors*. The term *genre* is used because it addresses how a multiplicity of individually expressive features can collectively be experienced as belonging to a particular class or identity (Frow, 2013). The vocabulary aims to articulate the expressiveness of smart wearables in interaction with wearers. Inspiration of the vocabulary takes on the existing work on *materiality of interaction* (Robles & Wiberg, 2010; Vallgårda, 2014; Wiberg, 2014; Wiberg & Robles, 2010) and *somaesthetic interaction design* (Höök, 2018). The works of these authors suggest that not only computation (e.g., algorithms) but also their material manifestation and the (embodied) interactions they afford can be seen as design materials, which should all be considered in the design process. With this in mind, we organized an exploratory workshop with nine design students who engaged in speculative design and enactments of possible interactions with smart wearables designed to help people out in different stressful situations. Our reflection on the students' work led to the articulation of *three genres of wearable partnerships*, each exhibiting particular physical and temporal forms and ways of affording interaction (known as the physical form, the temporal form, and the interaction gestalt; see Vallgårda, 2014, for detailed explanation). Below we provide a short recap of the definitions of these genres and how each of them can be described in terms of three adjectives denoting physical form, temporal form, and interaction gestalt (Table 1). Elaborate descriptions of these genres can be found in (Li, 2022).

Table 1. Vocabularies for the form-giving practice of smart wearables as partners (Li., 2022).

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

Organs refer to smart wearables that *translate* sensed signals into observable signals in an *ephemeral* manner to help the wearer be more aware of the situation and able to deal with it *reflexively.* When helping people deal with stress, this genre of wearables, like an artificial organ worn on the body, 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. They behave *ephemerally*—being a translational device—in an immediate response to a person's varying stress level. Thus, the interaction with such wearables is *reflexive*, which allows a person to intuitively manage stress, and by doing so, gain (bodily) sensitivity to stress.

Collaborators can engage the person in *collaborative* activities through their expressed *intent* and *negotiable* interactions. Such wearables are explicit in their *intention* in how to engage people in a collaborative activity. When doing so, their intentions might be perceived as being directional and indicative of different levels of influence, i.e., suggesting, nudging, or persuading. With the aim of a wearable collaborator to provide guidance in achieving a specific goal, it interacts with the person as part of a *procedure*. Such guidance may differ depending on which point in an action sequence the person is towards attaining a goal. Such wearables should also allow for *negotiation* with the wearers, enabling them to overrule or ignore the intention of the smart wearables, or adjust the way to achieve the shared goal. Different from smart wearables as organs, smart wearables as collaborators trigger a person to perform a particular sequence of actions rather than simply informing the person.

Mentors are smart wearables that have the sensitivity to teach their wearers (mentees) and show flexibility in the support they provide by learning from previous interactions. The *sentience* of such wearables (a label used to address the wearable's ability to interpret and learn) is exhibited through *wisdom,* which according to Ackoff (1989), refers to the ability to make decisions on whether and how to use the knowledge in specific contexts. In our case, the knowledge pertains to the understanding of the wearable of how to help someone cope with stress in ways that fit their needs and capabilities. We use the concept of *maturing* to indicate the capacity of a wearable to display maturing behavior over time by learning from the experience of mentoring the mentee. The interaction between mentor and mentee is considered to *co-develop*, in which both parties grow—the mentor becomes more of an expert on the mentee while the mentee learns more about his or her behavior (in our case, coping with stress).

In the following sections, we introduce a wearable prototype with the name *Grippy* as inspired by our previous work. We then describe how we have tested Grippy as a speculative probe in the field and how the results have deepened our understanding of human-wearable partnerships. The paper ends with discussions on the issues that affect the acceptance of Grippy as part of people's daily lives and perception of different genres of human-wearable partnerships, and the implications of smart wearables as partners in mental healthcare.

Grippy: *A Wearable Partner*

Grippy is a prototype of a smart wearable that embodies two genres of wearable partnerships (i.e., *organ, collaborator*) and, to some extent, the genre of a *mentor*. See Figure 2 for an impression. Grippy is 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 visualizes where stressful episodes have been experienced. The glove takes the form of a traditional glove (for left hand) and a strap-shaped glove (which can be worn by either left or right hand). Below we explain the design inspiration of Grippy and how its functions have been designed to provide support according to the three genres.

Figure 2. The Grippy prototype includes a physical glove (with a glove-shaped version and a strap-shaped version provided) **connected to an app on a smartphone.**

Design Inspiration

The inspiration of Grippy can be traced back to the graduation project by (Quaedvlieg, 2019), who presented the concept of a smart glove that functions as an interface between veterans with PTSD and a smart vest that can help the wearer to manage the data collected by the vest. It could also facilitate communication with a psychotherapist. Based on this concept, Grippy was developed as a functional prototype to help foster self-training exercises in everyday contexts. We drew inspiration from exposure therapy, a type of cognitive behavioral therapy (CBT) that is commonly used for the treatment of anxiety disorders. The principle of this therapeutic approach is *the conquest of our fears requires a confrontation with the things we fear the most* (McNally, 2007). Exposure therapy involves repeated confrontation with traumatic memories in the form of images, objects, activities, and situations (Friedman, 2015; Hembree et al., 2003), and by doing so, helps facilitate the emotional processing of traumatic memories and modify the erroneous cognitions that dominate patients' thoughts, feelings, and behaviors. Traditionally, exposure therapy is conducted in clinical environments under the guidance of a psychotherapist. With Grippy, we aimed to design a wearable partner that could actively engage people to find out and cope with everyday stress by means of exposure-training exercises. To explain Grippy's functions, we refer to the *three partnership genres* introduced in the section above.

Grippy's Functions

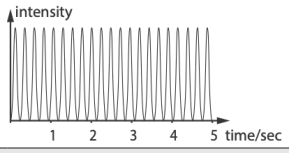
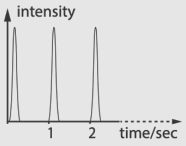
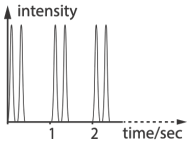
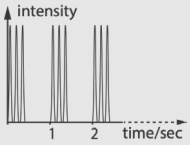
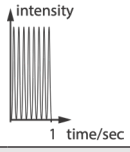
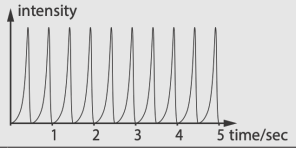
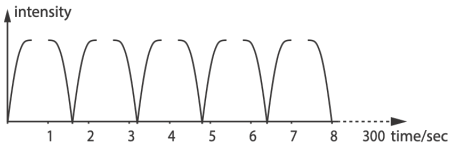
Table 2 shows the summary of Grippy's functions. Grippy makes use of a combination of sensors, that is, heart rate, acceleration, force sensor (used for sensing squeezing the glove), and the GPS function provided by the smartphone, to gather physiological, behavioral, subjective, and contextual data that are believed to be indicative of a person's stress and circumstances. In communicating back to the wearer, Grippy makes use of vibration patterns and visual representations. Below we elaborate on how these functions have been designed in such ways that fit with the descriptions of the three genres.

Organ: Stress Reminder, Haptic Interface and Inactivity Reminder

As an organ, Grippy can help the wearer become aware of stress by providing notifications and allowing a person to report stress. The *Stress Reminder* function is a 5-second vibration that reminds the wearer of potential stress arousal triggered by the heart rate sensor when it exceeds 130 BPM. When testing this function, we realized the heart rate sensor (Pulse Sensor) was easily disturbed by movements of the hand. We, therefore, set a relatively high BPM threshold (rather than 120 BPM). In addition, a minimum interval of one hour has been set up to avoid the wearer would receive this vibration signal so frequently that it would be annoying rather than helpful.

Upon receiving a stress reminder, the wearer can report on the experienced stress by squeezing a haptic interface located on the palm of the glove that is composed of a force sensor (Grove–FSR402) connected to a vibration motor. The wearer

Table 2. A summary of Grippy's functionalities.

Genres	Functions	Activation of sensors	Actuations (vibrations)
Organ	Stress Reminder	When the heart rate sensor senses the heart rate is higher than 130 BPM…	
	Interaction with the haptic interface	When the force sensor (located on the palm) senses low-level force…	
		When the force sensor senses medium-level force…	
		When the force sensor senses high-level force…	
	Inactivity reminder	When the accelerometer senses that the person takes less than 1000 steps within 2 hours…	
Collaborator	Challenge Prompt	When the GPS tracker senses that the person comes nearby a previously stressful place…	
	Comforting Support	When the challenge button is activated…	
Mentor	The annotated map	When the force sensor senses different levels of force…	, or is added on the map.
		When the challenge button is pressed…	is added on the map, replacing , or if there is any on the same spot.

can squeeze the glove to indicate the level of experienced stress; the harder the squeeze, the higher 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 gesture of squeezing fingers in the hand palm, or making a fist, is considered a natural way of expressing stress (Lefter et al., 2015; Neff et al., 2010) and has been used by other researchers (e.g., Guribye et al., 2016) in the design of tangible user interfaces that register one's affective status.

The *Inactivity Reminder* function is a 1-second vibration intended to remind the person to stay active and explore potentially stressful situations. This function is inspired by the previous study (Li et al., 2021) in which we learned how difficult it is for people with chronic post-traumatic stress to feel motivated to go outside and engage in social activities. The Inactivity reminder function works by sending out a vibration when the accelerometer (model: C1026B002F; located on the back of the wrist) senses that the person has taken less than 1000 steps within a two-hour timeframe. This threshold is decided by self-testing, in which the designer took a walk at a normal pace while wearing the accelerometer. This signal is intended to be informative; thus, no action on the device is required.

Collaborator: Challenge Prompt and Comforting Support

Grippy is designed as a collaborator that guides the wearer in stress exposure training. This is made possible by two functions, i.e., *Challenge Prompt* and *Comforting Support*. The *Challenge Prompt* function works as follows. Once Grippy senses—by means of its GPS sensor and the map on the smartphone—that the wearer is nearby a geographical location where he or she has earlier reported stress within a 25-meter radius of the location, Grippy 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 blue plastic case on top of the glove. When the challenge button is pressed to start a challenge, the *Comforting Support* function 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. The wearer can also start a training session on his or her own initiative.

Mentor: Annotated Map

Grippy provides support as a mentor by educating the person about the situations in which stress has been experienced by visualizing these situations on an annotated map. As shown in Figure 3 (right), we use fist-shaped icons of different colors 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 are immediately added to the map when the person decides 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). This map is built up from previous interactions and is therefore unique for each individual. By updating the annotated map in real-time, the wearer can 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. The annotated map endows Grippy with the potential to engage the wearer in *co-developing* interaction. However, note that Grippy does not display the characteristics of a mentor as being *sentient*. It does not have the expertise and sensitivity to help someone deal with stress, similar to how humans or animals (like helping dogs) might be able to. In addition, Grippy does not have the capability to show its *maturing* behavior since no machine-learning algorithms have been used to enable Grippy to learn improved coaching responses from historical interaction with the wearers.

Field Study

With Grippy as a speculative artifact, we conducted a field study to investigate how people experience wearing and interacting with a smart wearable during the day. The study was reviewed and approved by the Human Research Ethics Committee (HREC) of Delft University of Technology on October 30th, 2019. 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.

Participants

We recruited four master students and three university employees as participants, one of whom dropped out of the study after two days of wearing Grippy. Table 3 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 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 Ph.D. student with a background in Design Engineering. Frank was a visiting researcher at the time of this study who obtained his master's degree in Design Engineering. None of the participants reported having been diagnosed with a stress-related mental illness. Something that we will return to in the discussion section.

Procedure

At first, we arranged an introductory meeting with each participant that lasted about one hour, where we introduced the purpose of the study and the functions of Grippy. Informed consent was obtained from all participants. In the introduction meeting, the responsible researcher (the first author) guided the participant to try out Grippy and get familiar with its functions (Appendix 1). The instruction manual was adapted from the conceptual use scenarios of Grippy (Figure 3). A box was given to the participants to take home with them, including the glove, a smartphone with the App installed, chargers for the glove and the smartphone, and a notebook with the instruction manual (printed in A3) folded inside. Alice, Emily, and Frank were given the glove-shaped

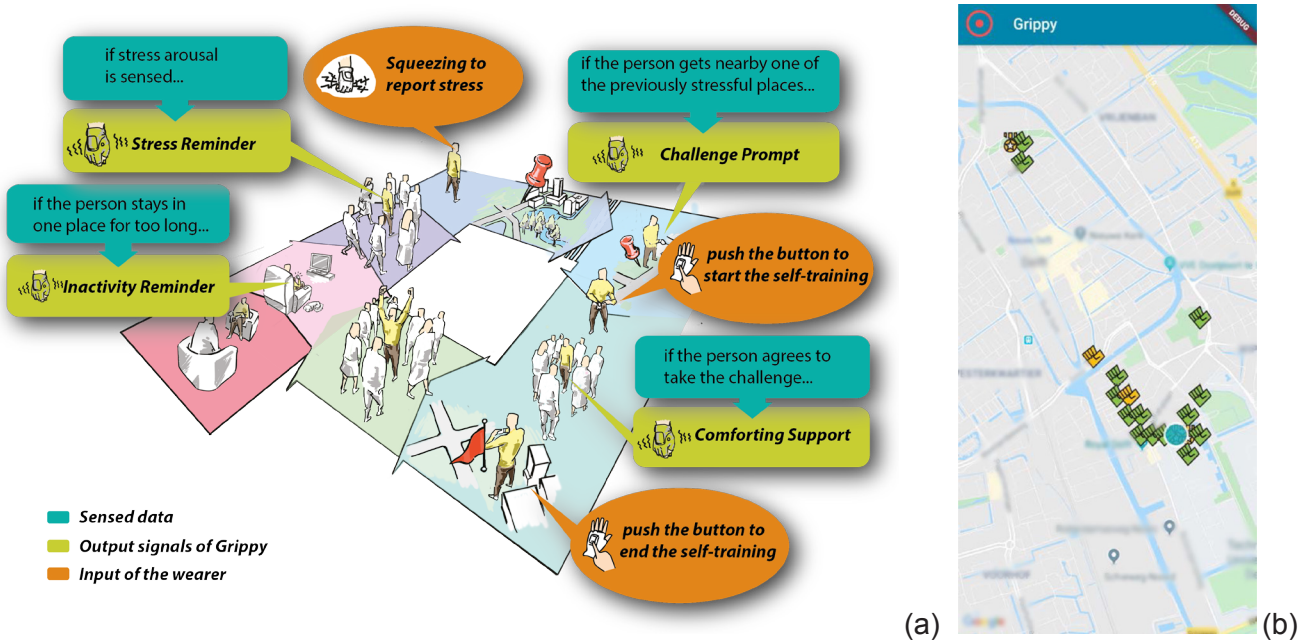


Figure 3. (a) Storyboard explaining functions of the smart glove, and (b) a screenshot of the smartphone application generated from the self-test.

Table 3. Basic information of the participants.

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

version of Grippy. Bella, Caroline, and Diane were given the strap-shaped version. Intermediate meetings (lasting from ten to twenty minutes) were arranged with the participants once or twice during the five days to ensure that Grippy was functioning well by checking the prototype and asking them if everything worked as expected. 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) the general experience of using Grippy for several days, (2) specific usability and use experience issues, and (3) the extent to which Grippy was experienced to be supportive in stress management (Appendix 2). Participants' accounts collected through these intermediate meetings and final interviews, were audio-recorded and transcribed afterward.

Data Analysis

At the start of the analysis, the responsible researcher read through all the transcripts to gain an overview and familiarity with the content. Then, an open-ended qualitative research method (Hsieh & Shannon, 2005) was conducted that led to 288 quotations. We first applied a top-down analysis on these quotations by using the *Objects with Intent* framework (Rozendaal et al., 2019), and as a second step, we interpreted the findings by using the three genres of wearable partnerships that resulted from an earlier study (Li, 2022, pp. 39-67).

The concept of Objects with Intent (OwI's) provides an approach for the design of smart objects that take advantage of the meaning of everyday things as the site of their intelligence and agency (Rozendaal et al., 2019). It includes an analytical framework informed by Leontiev's (1975) Activity theory and Dennett's (1987) theory of intentionality to help understand how OwI's mediate human activity as collaborative partners. This involves asking questions about the way people frame smart objects as a novel product category, how they become embedded in people's physical and social environments, and the extent they are able to transform people's behaviors and experiences. By applying this lens in this study, we are interested to find out how Grippy has been interpreted and interacted with as a smart

wearable, how the use of Grippy integrated in people's everyday activities (including their physical and social environments) and ways in which Grippy could provide support.

We also interpreted the data by using the three genres of wearable partnerships (Li, 2022) to gain an understanding of the extent Grippy has been experienced as an organ, a collaborator, and a mentor. Examining the extent the design intentions of Grippy matched or mismatched with participants' experiences of the design led to further reflections on the challenges in designing smart wearables that belong to particular partnership genres.

All the interview data has been anonymized and coded through the software Atlas.ti and later transferred into an Excel file which can be accessed through an online repository system (https://doi.org/10.4121/14672715).

Results

We first present the results of having applied the *Objects with Intent* framework to gain insights about how Grippy could fit into people's everyday activities as a collaborative partner for helping people deal with stress. We then share the insights gained by having reflected on the results based on the three genres of wearable partnerships.

Analysis Using the "Object with Intent" Framework

We start by presenting the results according to the themes of *framing, embedding*, and *transformation*. Table 4 shows a brief overview of the classified insights for each theme.

Table 4. 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 learned how Grippy was perceived and interacted with as a smart wearable in multiple ways concurrently. We provide an account of the ways in which participants framed Grippy as a *garment*, an *interactive system,* a *therapeutic device*, and as an *agent*, and describe how these different framings related to different 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 about wearing Grippy in public and showing 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 4. 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 4. Illustration of how the flexible strap-shaped version of Grippy can be worn with the haptic wrapped up and fixed 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 she used it for reporting on 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 *challenge button* 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 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 all the other 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 observed how participants perceived Grippy as a therapeutic device, which reflects the need for technological support in case of stress management. Given this 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, went shopping, or when relaxing in the weekend. 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 indicates how stress, and the need for a device to help you deal with stress, can be a sensitive and potentially stigmatizing topic that can impact the willingness to use 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, Alice and Emily brought up that Grippy reminded them of a dog. They both 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. She further mentioned how 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," and Emily commented that 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" whom 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 whom 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." This feedback indicates that a smart wearable with limited computational intelligence can trigger animistic connotations but may prove disappointing when the wearable does not seem to provide the support that is expected.

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 may become integrated in, or may obstruct, people's daily routines and what can make them socially appropriate or inappropriate.

Situated use. Given Grippy's understanding as a therapeutic device described earlier, 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 relation to Grippy being referred to as a garment, Alice considered Grippy as *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 in 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 how it could also feel awkward. Alice, Emily, and Frank felt positive about talking with others about Grippy. Alice would even show off Grippy to her friends. Emily told about a 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." 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 when talking about her graduation project and wanted to press the button to help her relax. She recalled at that moment: "…for some reason, my friend's eyes were all on my hand [on which Grippy was worn]." She felt like Grippy revealed her feelings to others as if saying out loud, "what you were talking about makes me uncomfortable." Emily shared a similar experience when Grippy started to vibrate when she ran into someone she was trying to avoid. She described that Grippy made her feelings *noticeable* to that person, and she felt that she was "getting red in the face and… everyone could see it."

Transformation

We also gained insights about how participants learned to use Grippy to help them deal with stress. Learnings from this perspective can help us to look into Grippy's potential for helping people change their behavior to improve their mental health.

Developing awareness. In some instances, Grippy helped participants to become aware of stress, which led to different evaluations. 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 in helping him recognize stressful moments, which "I

[he] normally would not check." However, being more aware of stress might also 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 were 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 was stressed.

Objectifying stress. We further 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 squeezing the glove to rate their stress. 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 vibrations of Grippy, these vibrations generally 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 that moment, for example, by *stretching the body or taking a short walk.* Similarly, Bella said that wearing Grippy helped her to look at her feelings more objectively. 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 realize how silly it was to be upset about a past event 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 like *stamping her feet* when she got angry but then less noticeable. Emily also appreciated how the vibration feedback of Grippy helped her *throw out* her negative emotions. Both Alice and Emily mentioned that after wearing Grippy for a while, squeezing had become a natural thing for them to do, something that they might start to miss after returning Grippy to the researcher. To our surprise, Bella used Grippy's vibrations elicited by the *Comforting Support* function to help her focus on meditation exercises. Something that was not foreseen in the design.

Grippy as an Organ, Collaborator, and Mentor

How people have experienced wearing and using Grippy has informed our conceptual understanding of Grippy as an *organ*, a *collaborator*, and a *mentor*. Table 5 summarises our findings that have been derived from critically reflecting on Grippy's design in relation to the three wearable partnership genres and discussing them in relation to participants' experiences of having worn and used Grippy during the field study.

Table 5. Analysis of Grippy's experiences as the three genres of wearable partnerships.

Vocabulary	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 (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 intensities 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, 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 into 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.

Grippy as an Organ

Grippy has been designed to *translate* sensor readings from the body into observable signals as they occur. Grippy does this by sending vibration signals immediately when it senses that the heart rate and the 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, and the second one is 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 sensitize them in terms of these different signals. Participants were confused about what Grippy's signals represented. This also included the 'Challenge Prompt' signal (described next for the Collaborator genre). The confusion may have been the result of perceptual similarities between the signals. 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 on it.

Grippy as a Collaborator

As a Collaborator, Grippy has been designed to allow the wearer to deal with potentially 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 out 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. 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 practice dealing with stress, nor would they break their daily routines just to follow Grippy's suggestions. In terms of Grippy being negotiable, participants mentioned how they would just ignore Grippy's encouragement for a self-training exercise. The intended collaboration could furthermore be reappropriated in the example where the *Comforting Support* function has been used by one of the participants to support her meditation sessions.

Grippy as a Mentor

In the Grippy prototype, we have included the *co-development* as an interactive feature of Grippy, in that it stores historical data on stress and uses that data to initiate interactive behavior (i.e., generating challenge prompts) and provides a means of inspection and reflection by visualizing 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 the historical experiences of the wearer. Finally, the inaccuracy of sensors (the heart rate sensor and GPS trackers in the phone) and the misreports of stress (e.g., caused by actions of squeezing when cycling for example) also added to the confusion about whether they were stressed or what caused their stress in these locations.

Discussion

We learned from the participants about the different ways in which Grippy could help them deal with stress, how Grippy triggered multiple understandings and interaction concerns as a novel product, and how the use of Grippy could be incorporated into, or could obstruct, daily activities. We also learned what functions did or did not trigger the participants' perception of the three genres as we had intended. In this section, we discuss the impact of usability issues on the perception of the vocabulary and genres in the design. We also reflect on the design implications of such smart wearables in mental healthcare.

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 and also helped them *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 did not engage in self-exposure training as we had intended with the design. We further noticed how Grippy was used to *release stress* through 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 action on stress. However, we acknowledge the preliminary state of the technology and the work that still needs to be done to realize this potential.

People's understanding of Grippy as a smart wearable partner involved multiple perspectives that we could unpack in relation to interaction concerns. Such an understanding can help guide its future development as an improved integrated design. Previous work on the design and experience of smart objects (see the work done by Cila et al., 2017; D'Olivo et al., 2020; Laschke et al., 2015; Marenko, 2014; Rozendaal et al., 2019) address aligning and reconciling the intelligent behavior of objects with the meanings associated to them. We continue this discussion by elaborating on the different ways people framed Grippy as a smart wearable (i.e., as a therapeutic device, interactive system, garment, and agent) before discussing issues related to its integration.

Understanding Grippy as a therapeutic device triggered associations related to needing support. The extent to which the need for support is sympathized with, and welcomed, seems to have determined its acceptance and use. Although the results indicate that wearing and using Grippy helped some of the participants to become more aware of their stress and to reflect on their possible underlying causes, we noticed that Grippy was not well accepted by participants who consider themselves to be optimistic or capable of

dealing with stress. Furthermore, we found how the use of Grippy could lead to embarrassment when people believe others might see that a device is being used to help manage their stress. We also realized how the use of Grippy led to disappointment when the wearable can increase one's awareness of stress but does nothing to help 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, stigma is also believed to be a problem that is related to social exclusion or discrimination for people with stress disorders (Corrigan & Watson, 2002; Hipes & Gemoets, 2019), which indicates more cautious and ethical approaches when designing with and for them.

The understanding of Grippy as an interactive system raised other concerns. For instance, difficulties in distinguishing between different vibration signals caused problems in picking up what kind of signal has been triggered and produced inaccuracies in reporting on one's levels of stress. Furthermore, the implementation of a smartphone app as part of the interactive system was considered cumbersome in use because it demanded attention and required additional actions compared to the use of the smart glove as part of the interactive system. Interacting with touchscreens on smartphones may not be that well-compatible with the intuitive physical interactions made possible by the glove. These findings flag concerns about usability and the compatibility of multiple elements that make up a smart wearable system, and its design may benefit from a peripheral interaction approach, for instance, as proposed by Bakker et al. (2015).

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 was perceived as something cool but also as manly and sporty and raised concerns about its convenience to wear as a glove that people normally wear for hygiene and protection purposes. Reflecting on the design and people's responses to it, Grippy might have been more wearable when designed with a particular style in mind, which requires the use of distinctive decorative elements (to fit a particular style) but more importantly, the miniaturization and integration of technology in the fabrics themselves. Relevant work can be found in the domain of e-textile or smart textiles (Komolafe et al., 2021). These issues have been found important as they can block or promote daily use. Therefore, the general design principles of wearable technologies, such as washability, aesthetics, and comfort (Gonçalves et al., 2018; Motti, 2020; Rotzler et al., 2021), should also apply to designing smart wearables as partners.

Understanding Grippy as an agent involved the perception of it being able to communicate with you. Some participants applied an animistic metaphor to describe the companionship that Grippy provided them by comparing Grippy to pets or close friends, but this metaphor broke down when they experienced the wearable could not support them in the way they anticipated. 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 overestimate the level of intelligence of smart wearables. For a discussion on this topic, see de Visser et al. (2016) and Looije et al. (2010).

Another point of reflection concerns the danger of adopting a positivist perspective of Grippy's sensing capabilities. It has been challenging to sense stress through the physiological, behavioral, subjective, and contextual data gathered by interacting with the smart glove. As mentioned by the participants, using GPS locations seemed not representative of one's stressful situations, which could take the forms of a memory, a thought, or a conversation, which are not bound to a particular place. To this point, Dourish (2004) argues against a positivist angle that assumes context is representational and predetermined. As he proposed, context should be taken as an emergent feature of the interaction that is not separable from, but defined by, the ongoing activity at the moment. 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. Grippy's ability to enable a person to report on their own stress as a means for self-reflection embraces this perspective to some extent.

Integrating solutions to all these aspects into a fully integrated design is a grand design challenge. We realize 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. Only when the design is developed to that level would it make sense to reintroduce it to veterans with PTSD to test whether or not they would find such a product helpful.

Perception of Formgiving Vocabulary and Genres of Partnerships

Summarizing the analysis of Grippy as a partner, we see how usability issues interfered with the recognizability of Grippy's prototypes in terms of the vocabulary and genres of wearable partnerships. For *organs*, its signals should have correspondence with bodily changes that it intends to communicate: imagine how the stomach signals (by cramping) that you might have eaten something wrong or too much, or the skin creates goosebumps and starts shivering when you are in a cold environment for too long. The vibrations elicited by the glove on the back of the hand have not been sufficient to engage the person in such an intuitive reflection. 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. This 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 triggered by Grippy undermined its perception as a *mentor* to co-develop with the wearer, as, for that to work, signals should be trustworthy.

Design Implications for Mental Healthcare

Our work provides insights for developing novel interventions for stress management that utilize 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 et al. (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, 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 self-reflection on their historical experiences of coping with stress. In our study, 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.

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 nudging, is controversial (see, e.g., Hekler et al., 2013) because of the ethical concern that any instruction of new behavior might undermine one's autonomy (Purpura et al., 2011). This ethical concern also applies to smart wearables. Grippy provides a base to imagine 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 behavior of reminding people whenever it thinks the person is stressed is not well appreciated during social conversations or encounters. 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 person deciding to visit a psychologist when acknowledging needing help.

What emerged from the field study seems to point to a different aspect of the challenge of sensing stress that sometimes people cannot account for their own stress (whether they are stressed and what causes it) or do not want to be involved in reflecting on their stress. This is also confirmed by other researchers (e.g., MacLean et al., 2013), who found that one's awareness of stress can further increase it. A more sensitive and ethical approach is needed to design interactions with smart wearables that help people deal with stress without raising negative connotations. To achieve this, design strategies from Positive Design (Desmet & Pohlmeyer, 2013) may help reduce or mitigate these negative impacts by emphasizing how a design can evoke positive emotions or moods. The playful experience of squeezing Grippy, as reported by one of the participants, sheds some light on what a stress-releasing, as well as positive interaction with smart wearables, could be like.

Even though the current design of Grippy is not yet ready for people with persisting stress management needs, we see the potential of integrating smart wearables in mental healthcare settings. eHealth solutions, such as 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 as a tool for psychologists to help patients practice exposure therapy by themselves, extending the availability of psychotherapy outside of the clinic. This could support the recovery of patients while decreasing the workload of psychotherapists, thereby lowering healthcare costs as well.

Limitations

We would like to address some of the technical challenges we encountered when building the prototypes of Grippy. Using commercially available electronics (such as sensors, processors, batteries, etc.) allowed us to build prototypes within the time and budget constraints of the project. However, they were not optimal considering our design aim and required us to make several compromises. For instance, we needed to set a one-hour minimum time interval for heartrate signals because the raw data produced by this sensor is easily disturbed by body movements. We also needed to accept the possibility of the occurrence of false challenge prompts indoors by having used GPS trackers, and due to the relatively large technical components used, the physical prototype turned out to be bulkier than we would have liked. Still, the lessons learned by having deployed a working prototype in the field had great merit. The experiences gained from people interacting with the Grippy prototypes in real life allowed us to generate useful insights about the conceptual understanding of human-wearable partnerships and their potential in stress management. A foreseeable next step would be to work further on technology refinement and integration. By deploying such a more advanced prototype in the field for months or longer, we can learn how Grippy provides a helping hand to people who suffer from stress as a chronic condition.

We should also note the gap between the participants of this study and our original target users of veterans with PTSD for whom the design of Grippy was originally intended. The experience assessment of the Grippy prototype reported on in this study was performed with university students and employees rather than veterans with chronic PTSD. Given the preliminary

state of the concept and prototype, it was deemed unethical to involve veterans with PTSD in this study. However, the value of the study remains, as it addresses the general phenomena of dealing with stress as it occurs and is experienced in real life, which reflects, if not all, partial realities faced by veterans with chronic PTSD. Still, differences between the daily hassles reported by the participants (which are generally mild and short-term) and trauma-related stress experienced by veterans (which can be overwhelming and are chronic) caution us to generalize the results as applicable to this target group. Evidently, the road toward smart wearables that are readily helpful for veterans with PTSD is still long.

Conclusion

This paper 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 the expressiveness of such partners as *organs, collaborators*, and *mentors*. 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 and use of Grippy. In particular, Grippy as a therapeutic device might trigger social stigmas 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 for stress management.

Furthermore, this field study has provided 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 was 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, 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 for generating insights about the conceptual understanding of human-wearable partnerships and its potential in stress management.

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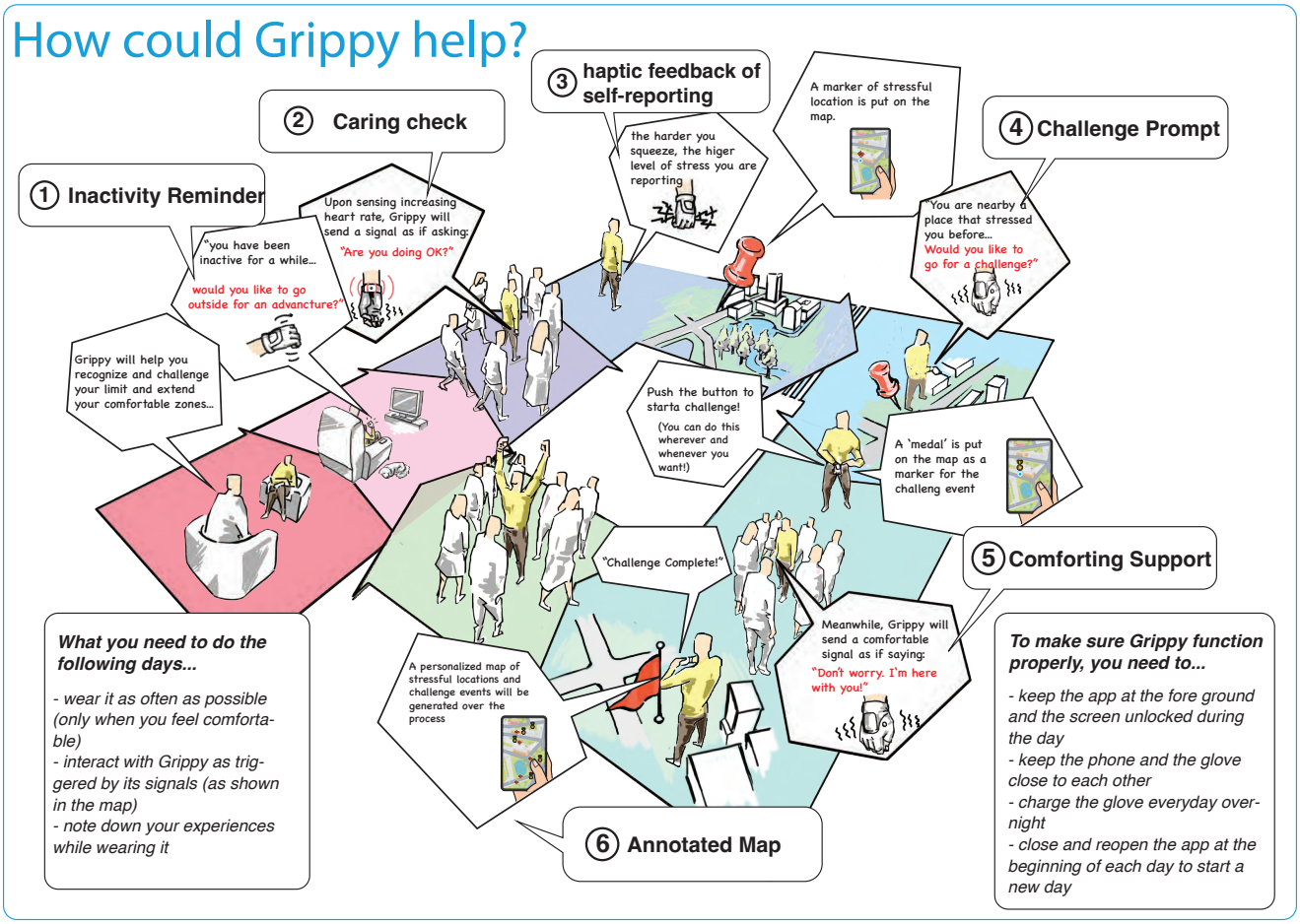
Appendix 1: *Instruction Manual for Participants*



Appendix 2: *Script of the Interview*

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 a 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 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 glove and App separately
  - Its behavior (What it does and how it behaves?) *follow-up about 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
- 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?
- 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)
- Grippy's signals and visual communication *follow-up on 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, colors and symbols of the App?
- Grippy's controls *follow-up on glove and App separately
  - Glove: How do you like 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?
  - The activity you were engaged in that moment *follow-up in terms of how Grippy integrated or disturbed this activity
  - The physical setting (indoor/outdoor, heat, cold)
  - 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
- Can you describe this specific episode?
- How did the glove do to make you aware? *this question might be repeated when participants were reflecting on other episodes.
- 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 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)?
- What did you do?
- Did it work for you?
- What was your motivation then?
- 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?
- In which situation would you accept the challenge?
- What did you do then?
- Did it work for you?
- Can you share with me an episode?
- 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)?
- What are they?
- How did the glove help you to learn this?

Part IV: *Debriefing*

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

- Is there anything interesting or important that have 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.