M12 BSc. Thesis: Exploring the Impact of Wearable Devices on Perceived Stress and Health Anxiety: A Mixed-Methods Approach

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Abstract

Wearable technology, particularly smartwatches, is becoming increasingly popular for health monitoring and fitness tracking. However, limited research is conducted on the psychosocial impact of these wearables. This study explored the psychosocial effects of wearable smartwatches on perceived stress and health anxiety. The research questions aimed to determine if and how the presence of a wearable smartwatch affects these constructs and to explore the participant's subjective experiences using a mixed methods approach.

This study used mixed methods within-subject replicated counterbalanced AB design in which 26 Dutch participants aged 19 to 59 (84.6 % female) were part of both conditions for one week, either wearing a smartwatch or not. Some participants wore the smartwatch in the first week, and some wore it in the second week to counterbalance the study. Quantitative data was collected using daily and weekly questionnaires using the PSS-10 and SHAI-14 and was evaluated using linear mixed models. After the quantitative data collection, which took two weeks, a selection of participants took part in the qualitative semi-structured interviews.

The quantitative analysis revealed no significant effect of the smartwatch's presence on perceived stress or health anxiety for the overall sample. The qualitative interviews provided deeper insight into the participants' experiences and differences. While most participants reported no or limited change, some expressed decreased stress and health anxiety due to increased awareness and comforting feedback from the smartwatch. Some participants mentioned an increase in their perceived stress, which was not reflected in their scores.

These findings suggest that while smartwatches can offer potential benefits their impact on perceived stress and health anxiety is complex and varies between individuals. Future studies should consider a longitudinal design with a sequential exploratory approach to better assess the effects of wearables on perceived stress and health anxiety. Additionally, including individuals more susceptible to these psychometric constructs could provide deeper insight into the potential impact and mechanisms involved.

Exploring the Impact of Wearable Devices on Perceived Stress and Health Anxiety: A Mixed-Methods Approach

Wearables have become increasingly popular over recent years, and more and more units are shipped and sold yearly, with an estimated 490 million units sold in 2022 (Laricchia, 2024). This popularity is understandable when considering the many functions and uses they can have. Wearables like smartwatches can, for example, measure sleep, physical activity, and calorie intake and even give feedback on improving these (Etkin, 2016). Recently, these wearables have been used to give stress feedback by using a person's heart rate variability (HRV) (Pakhomov et al., 2020). Several studies have explored the effectiveness of wearables in increasing physical activity or improving sleep (Smith et al., 2020; González Ramírez et al., 2023; Buckingham et al., 2020; Klimek et al., 2023). However, few studies have considered these wearables' effect on our psychosocial health, specifically perceived stress and health anxiety (Ferguson et al., 2022; Lupton, 2013). The current study aims to explore the psychosocial effects of wearables on different individuals in the context of stress and health anxiety by using a mixed methods approach within subject replicated counterbalanced AB design in which participants wear a smartwatch for one of the two weeks of the experimental period.

Wearables: definition, advantages and disadvantages

Wearables, typically used as mobile health technology, are devices or apps used to track one's health. Common wearable devices are accessories like smart bracelets, smart watches and armbands. Wearables continuously measure physiological signals and give users insight into their daily activity and experiences (Lu et al., 2020; González Ramírez et al., 2023). When wearables are embodied by the users, being perceived as an extension of themselves or their body, they can significantly positively affect daily physical and mental health (Nelson et al., 2024). Studies found increased physical activity and reduced psychological distress (Choudhury & Asan, 2021; González Ramírez et al., 2023; Ferguson et al., 2022). However, there have also been some critiques of the effects of wearables. Some studies have reported empirical evidence suggesting that prolonged use of wearables reduces the enjoyment of physical and other activities, which can reduce intrinsic motivation to complete such activities, leading to a negative effect in total (Etkin, 2016; Toner, 2018). This aspect of both positive and negative aspects is also reported in a study by Kanstrup et al.

(2018), in which it was found that vulnerable young adults felt feelings of failure when not achieving their step goals or were obsessed with it. Furthermore, some expressed a strong feeling of competition, increasing experienced stress symptoms. Another study found that the use of wearables and the data they provided resulted in significant confusion, reducing their use or stopping use completely (Nelson et al., 2020).

In a systematic review of systematic reviews and meta-analyses, Ferguson et al. (2022) examined the effectiveness of wearable activity trackers for improving physical activity and physiological and psychosocial outcomes. In this study, many positive effects of increasing physical activity and some effects of improving physiological outcomes were found. Very limited reviewed analyses focussed on the psychosocial effects of these physical activity trackers. Four studies focused on quality of life; the only other review focused on disability and pain. This led to Ferguson et al. (2022) concluding that no, or only a weak positive effect on emotional well-being was apparent in this review. This lack of significant results led to the paper by Ferguson et al. (2022) suggesting future research to focus specifically on the effects of wearable activity trackers on psychosocial outcomes. Among psychosocial outcomes, critical factors which can be considered are stress and health anxiety.

Defining and measuring stress

Defining stress and discussing how it is measured is essential. Stress is described as the health pandemic of the 21st century by the World Health Organization (Fink, 2017). Stress is an individual's reaction to a stressor or stimulus (Klimek et al., 2023). A stressor is an external situation or event affecting a person, leading to psychological, behavioural, or physiological stress response. The psychological stress response could also be called "perceived stress," as it is the stress the person consciously experiences and can report on (Wright et al., 2020). In this study, 'stress' will be used to describe the physiological response to stress and 'perceived stress' will be used to describe the psychological response to stress.

Stress can be measured by looking at changes in parasympathetic activity, which can be indirectly measured with, for example, heart rate variability (HRV). HRV indicates the fluctuation of the length of heartbeat intervals, where, in general, a lower HRV indicates a higher stress response and a higher HRV indicates a more relaxed response (Kim et al., 2018; Geus & Gevonden, 2024). Perceived stress is most often measured using (self)-administered questionnaires, for example, the Perceived Stress Scale (PSS), which is widely considered reliable (Cohen et al., 1983). Perceived stress can be affected by many external and internal

events. Ranging from major life events to minor daily hassles (Wright et al., 2020). Some studies have found evidence of increased perceived stress in individuals when wearing wearables. The study by Attig and Franke (2020) questioned former users for abandonment reasons of their fitness-tracking devices through a questionnaire. They found that several participants mentioned feeling increasingly stressed by a wearable fitness-tracking device. An experimental study by Kanstrup et al. (2018) examined the influence of activity tracking on health engagement in vulnerable young adults. They found evidence for increased perceived stress when using wearables. This perceived stress was a side effect of feelings of competition which the participants experienced. However, both these studies found these results to be side effects, and perceived stress was not the focus of the study.

In contrast, this study will focus on the effects of wearable devices on perceived stress through a mixed methods within-subject replicated counterbalanced AB design on healthy adults. This will allow for a deeper understanding of the potential effects of wearables on perceived stress. Considering the potential impact of wearables on perceived stress, it is also important to explore their effect on health anxiety, another relevant psychological construct.

Health anxiety

Health Anxiety is a psychological construct and occurs when individuals interpret bodily sensations as indicators of severe disease or health problems. This is expressed as excessive worry and anxiousness about an individual's health. An example would be if an individual would interpret a headache as a symptom of a brain tumour. Levels of health anxiety can vary, and severe levels of health anxiety are seen as hypochondriasis and illness anxiety disorder (Salkovskis et al., 2002). In literature, health anxiety, illness anxiety and hypochondriasis are all names used for the same construct; however, illness anxiety and hypochondriasis often refer to pathological levels of health anxiety (Lebel et al., 2020; Salkovskis et al., 2003). As this study does not include individuals with clinically diagnosable mental illnesses, this study will use the name health anxiety when discussing the construct.

Health anxiety can significantly impact an individual's life and lead to increased costs in healthcare due to repeated doctor visits and examinations (Espiridion et al., 2021). Health anxiety has an estimated prevalence of between six and ten per cent in the American population (Noyes et al., 2005). Studies have discussed the potential negative impact of mobile health or m-health technology in the context of Health anxiety. M-health technology includes apps for counting calories and steps and wearables capable of measuring HRV and

blood pressure. These studies considered the possibility of increased health anxiety with smartwatch use, showing the need for further research into these effects (Kamel Boulos et al., 2014; Wiederhold, 2015; Lupton, 2013).

Two studies exploring the function of using patient portals in hospitals, which track and relay personal health information to the patient directly, found an increase in patient worry and anxiety when not wholly understanding the results (Giardina et al., 2015; van Kuppenveld et al., 2020). A similar result can be hypothesised when considering the use of wearables and the feedback they provide (Choudhury & Asan, 2021). If wearable devices give biofeedback like HRV, it is possible that users can misinterpret this information, leading to unnecessary worry and an increase in Health anxiety symptoms (Choudhury & Asan, 2021).

One study by Conboy, Flood, and Power (2018) explored the effects of mobile health apps and devices on health anxiety with a quantitative and qualitative questionnaire based on the Short Health Anxiety Inventory (SHAI) and using a snowball convenience sampling method. The study found qualitative evidence for an increase in health anxiety symptoms in the users of m-health apps but a lack of a significant quantitative effect. The study called for more in-depth research into the effects of wearables on health anxiety using a pre-post study (Conboy et al., 2018).

The cognitive theory of health anxiety (Salkovskis et al., 2003) states that health anxiety results from processes which uphold the negative interpretations from which the anxiety stems. This would mean that it is a cycle in which the effects and symptoms become worse over time. This process is driven by some common cognitive processes found in many individuals, like the selective attention bias or physiological responses like the heightened experience of bodily sensations (Salkovskis et al., 2003, p.356). Individuals suffering from health anxiety will look for reassurance to calm down; this can result in either a temporary decrease of health anxiety symptoms or create additional anxiety and fear. Considering these aspects and the constant health updates provided by wearables, it is hypothesised that a wearable can both increase and decrease health anxiety. Other studies looked at the effects of health internet searches on health anxiety. These studies by Fergus (2013) and Dolan and Fergus (2014) found that online health searches increased health anxiety in individuals, raising questions about the effects of constant health information from wearables on health anxiety. Given these considerations and the gaps in existing research, our study aims to explore the psychosocial impacts of wearables by focusing on inexperienced users and supplementing quantitative findings with qualitative interviews.

Bridging gaps in research

Until now, limited research has assessed the psychosocial aspects of wearables. The only other study exploring the psychosocial impact of wearables is on health anxiety by Conboy, Flood, and Power (2018). However, they used an online survey using 38 questions with either a multiple-choice response or free-text qualitative responses. This study consisted only of participants who were already regular m-health technology users. The design of the study reported here used inexperienced participants who have not used this technology before; therefore, the impact of the wearable can be more clearly assessed.

Furthermore, the qualitative interview will provide more detailed and clear information from participants than a qualitative questionnaire, as there is room for follow-up questions and clarification. This study can provide valuable information and insight into the real-world impact of wearable usage. This information could provide a basis for future studies to explore specific impacts discovered in this paper.

The current study

This study explored the effects of wearables on individuals' perceived stress and health anxiety. This study used a mixed methods within subject design in which each participant was their own control using a repeated AB counterbalance (Lane & Hursh, 2013; Lim & In, 2021). In this design, each participant was part of both conditions of the study, which gave a better understanding of the effect of the smartwatch on the participants. Each participant crossed over from phase A (smartwatch present) to B (smartwatch not present) or vice versa. The study used the experience sampling method or ESM as it provided the best basis to assess the subjective experience of subjects with limited intruding aspects. This design had the crucial advantage that subjects were measured in their typical day-to-day life rather than in an experimental lab setting or with a one-off questionnaire, which suited the aim of this study. It allowed for a more in-depth view and a more detailed and expansive data collection for each participant (Myin-Germeys & Kuppens, 2022). This data was collected by having subjects assess their experience daily using self-assessment questionnaires. This method was a good representation of the real-world situation as this would also be the normal condition in which wearables are used.

In the quantitative data collection phase, participants were measured for two weeks, with the first week filling out a daily self-assessment questionnaire and the second week

repeating the same daily self-assessment questionnaire but now wearing a smartwatch daily. A second group of participants started with a smartwatch in week one and not in week two, counterbalancing the study.

Qualitative data collection was done through semi-structured interviews after the two weeks of quantitative data collection. In this qualitative interview, participants were asked about their subjective experience of the experiment and additional questions to elaborate on their experience. Unlike the study by Conboy, Flood, and Power (2018) and Attig and Franke (2020), this study only involved participants without experience with smartwatches, adding the novelty of first-time experiences of the participants.

Considering the previously discussed literature, there were three main goals this study focussed on. Firstly, this study explored the potential effects of wearables on subjects' perceived stress. Secondly, this study aimed to explore the effect of wearables on Health Anxiety. And finally, this study explored the potential effects of wearables on perceived stress and health anxiety through qualitative accounts. Three research questions were established to achieve these goals. It was necessary to quantitatively examine the potential effects of wearables on perceived stress and health anxiety and supplement the potential findings by integrating the qualitative interview analysis. This answered the question (R1): *How does the presence of a wearable smartwatch affect perceived stress in individuals?* and (R2), *How does the presence of a wearable smartwatch affect health anxiety in individuals?*. Then, it was essential to review participants' subjective experiences and perceptions regarding their use of wearable smartwatches. This allowed for a better understanding and painted a complete picture of the potential effects. This gave us the third and final research question (R3): *What are the subjective experiences and perceptions of individuals using wearable smartwatches related to perceived stress and health anxiety?*.

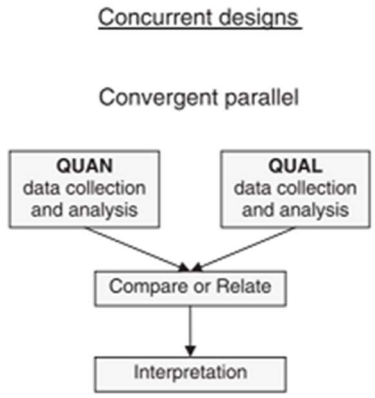
Methods

Research design overview

In the design of this study, the quantitative data was collected before the qualitative data. A selection of the participants took part in the qualitative data collection; the selection method is described in the qualitative data analysis section.

This study used a concurrent and triangulation within-subjects design. In this design, illustrated by Bishop (2015) in Figure 1, the quantitative and qualitative data are analysed simultaneously, meaning that the results from the quantitative data analysis do not affect the qualitative data collection method or vice versa. Furthermore, there is no emphasis on either the quantitative or qualitative data, and finally, it means all participants participate in the same condition. The quantitative data was collected by self-administered daily repeated questionnaires, and the qualitative data was collected through semi-structured interviews. As this study is a combined project the information regarding the SAM assessing threat and challenge in the context of stress will be excluded from the methods, analysis, results, and discussion.

Figure 1
Illustration of a Concurrent Design



Note. Figure taken from Bishop (2015). QUAN and QUAL stand for quantitative and qualitative, respectively. The separation and positioning of the boxes in the illustration represent the simultaneous collection of data, and neither data is prioritised.

Participants

In total, 26 adults aged 19 to 59 participated in this study. Participants were either students, working students, full-time workers, or unemployed. All participants were from the Netherlands. Each participant participated voluntarily and signed an informed consent form at

the start of the study. The whole study was conducted in Dutch. The University of Twente Ethics Committee gave ethical approval under request number 240270 A selection of participants participated in the qualitative data collection; this selection procedure will be described in the participant recruitment section.

Participant Recruitment

The study aimed to have as many participants as possible within the available materials and time limits. Recruitment for the quantitative component halted when the maximum number of participants within these limits was reached. The number of participants for the qualitative components was limited to the time available for the researchers to conduct the interviews within the data collection timeframe. The inclusion criteria for the study were that participants spoke Dutch and were in possession or had access to a mobile device with which they could fill in the questionnaires. Exclusion criteria were having a serious psychological condition or having regularly worn and used a smartwatch device in the months before the study.

A convenience sampling method was used to collect participants for the study, the same participant pool was used for both data collection phases. All participants were contacted in person or via text and were all friends and family of the researchers. Forty-eight individuals were contacted to participate, of which 26 (54.2%) participated in the study. For the qualitative interview, researcher 1 approached nine individuals, of whom seven (88.9%) agreed to participate. Researcher 2 approached ten individuals, and nine (90%) agreed to participate. Unfortunately, two participants were excluded after completing the quantitative and qualitative data collection, as they revealed during the qualitative interview that they regularly use a smartwatch.

When participants agreed to participate, they also agreed to participate in the study's quantitative component for two weeks, fill in daily questionnaires using the TIIM phone application, and wear a smartwatch for one of those weeks. When agreeing to participate in the qualitative component of the study, participants agreed that they could be contacted by the researchers for an interview. Participants agreed that they were allowed to stop their participation in the study at any time without explanation, upon which all their data would be removed. Only one participant received compensation for participation in the form of 3.5 SONA credits, which are compulsory subject-hour credits for psychology students at the University of Twente.

Data collection

The study consisted of both a quantitative and qualitative data collection phase. Both data collection phases used different procedures and materials. Therefore, this section will be split into the quantitative and qualitative data collection.

Quantitative data collection

The quantitative data was collected from March 17, 2024, until the 21st of April 2024. In the quantitative data collection phase, the participants were divided into four starting groups, each starting one week after the other. This was done due to the limit of seven Garmin devices, which required a weekly transfer of the devices from one participant to another. After agreeing to participate, the participants were asked if they preferred one of the four starting groups. Participants without a preference were assigned a group based on logistical availability. Participants were put into their preferred groups if possible. Which participant started with a smartwatch and which participant did not was assigned within each group at random. An additional description of the participant instructions can be found in Appendix 5.1.

During quantitative data collection, the participants were given either a Garmin Forerunner 255 or Garmin Vivosmart 4 for one week of the data collection. Each Garmin was fitted with functions the participants were told not to change. These functions were Heart rate, HRV, Stress, Sleep, respiration, Ox, and Health Snapshot. Only two participants changed the functions; one participant added his heart rate to his home screen, and one participant added the run activity tracker. The participants were shown how to see their daily and weekly stress levels, as a question about this was included in the questionnaires.

The Garmin Vivosmart 4 required the participants to download the Garmin Connect app on their smartphone (https://play.google.com/store/apps/details?id=com.garmin.android.apps.connectmobile&hl=en_US) to see these measurements. The participants received the charging cable and the information booklets inside the same box in which the smartwatch was given.

The researchers used the Twente Intervention and Interaction Machine (TIIM) software (https://play.google.com/store/apps/details?id=nl.bmslab.utwente.tiimapp&hl=en_US) to construct and distribute all questionnaires for the quantitative data collection. Using TIIM, participants could fill out the daily and weekly questionnaires on their smartphones. The

TIIM software included the ability to preset opening times for the questionnaires. This function set all questionnaires to open at 18:00 every day. Unfortunately, this malfunctioned for the study's second, third and fourth starting groups. This meant that the researchers had to manually time and open the questionnaires every day at 18:00. As a result, some questionnaires were opened at different times, ranging from 17:00 to 20:00. Besides notifications, the researchers sent an additional reminder via text when the questionnaires were available.

There were two types of questionnaires: daily questionnaires asking about the day and weekly questionnaires asking about the week. The questionnaires had a text prompt above the questions indicating this. Figure 2 shows an example of the participants' screen when answering a question from the questionnaire. The questionnaires were named Day 0, Day 1 up to Day 14 and Week 1, or Week 2.

Figure 2

Example participant screen

Note: This is a screenshot of what the participants would see when completing the questionnaires on their phones using TIIM. The bold blue text is the question, and the grey subtext explains the context in which the question is asked.

The daily questionnaires measured the participants' perceived stress using the PSS-10. The weekly questionnaires measured the participants' Health Anxiety using the SHAI-14 and perceived stress using the PSS-10. Each questionnaire started by asking if the participant wore their smartwatch that day. If they indicated "yes", the next question would ask the participant to fill in their average stress score from that day or week. This was done to prompt the participants to look at their stress levels and reflect on the stress feedback from the smartwatch before filling in the questionnaire, similar to an approach from Montagna et al. (2021). If the participant responded "No" to the question, the follow-up question was skipped, and the participant automatically continued with the first question of the PSS-10.

Perceived Stress Scale. Perceived stress was measured using the PSS-10, which has a widely accepted Dutch-translated version, but this version's psychometric properties have yet to be assessed in the scientific literature (Mapi Research Trust, 2023). The questionnaire consisted of 10 questions in which respondents were asked how often they felt a certain way the last day or week with a five-point scale ranging from 0 (“never”) to 4 (“very often”). The PSS-10 in original English has been shown to have good internal consistency and a Cronbach’s alpha of .83 (Lee, 2012). The complete questionnaire can be found in Appendix 2. The Cronbach's alpha of the daily translated PSS-10 questionnaire in this sample was .66, which is considered acceptable.

Short Health Anxiety Inventory. Health anxiety was measured weekly using the SHAI-14 (Te Poelman et al., 2017), translated into Dutch. For the translation, the research team used chat-gpt from open AI (https://chatgpt.com), which the two researchers adjusted and assessed independently. The two adjusted versions were then evaluated and discussed by both researchers, upon which a combined and agreed-upon final version of the Dutch SHAI-14 was created. The SHAI-14 consists of 14 statements in which the participant must pick the most suitable to their feelings, with scores ranging from 0 to 3. An example question is “I worry about my health” or ‘Ik maak me zorgen om mijn gezondheid.” and the answers are 0 “Never”, 1 “Occasionally”, 2 “Much of the time”, and 3 “Most of the time”. The complete questionnaire and its translation are found in Appendix 3. The SHAI-14 has been shown to have good internal consistency and a Cronbach’s alpha of .92 (Te Poelman et al., 2017). The Cronbach's alpha of the weekly translated SHAI-14 questionnaire in this sample was .63, which is considered acceptable.

Additionally, the SAM was used to assess stress appraisal measures, but this falls outside the scope of this study and will thus not be discussed further.

Qualitative data collection

The qualitative data collection consisted of a semi-structured interview. Participants were invited to participate in the qualitative interviews after the quantitative data collection phase. Participants were approached at random until the maximum number of feasible interviews within the timeframe was reached (n=16). All interviews were conducted in the last week of data collection. Nine interviews were conducted in person and seven online based on participant preference. The Microsoft Teams recording, and transcription software were used for interviews conducted online. Microsoft Word was used to record and transcribe interviews conducted in person. The researchers checked and adjusted all generated transcripts using the audio recordings of the interviews. The materials used for this were the audio recording from Word, the generated transcript from the Word audio recording and a headset to replay the recording and edit where necessary.

The qualitative interview scheme consisted of 9 questions and some predetermined follow-up questions. The researchers designed the questions to gain additional insight into how participants used the smartwatches and their subjective experiences. After the first interviews were conducted, some questions were added or adjusted based on the researchers' experiences. An example of an added question inquired if participants could imagine the advantages and disadvantages of using smartwatches to track one's health. This question gave a more comprehensive range of opinions regarding using smartwatches for health tracking.

Appendix 4 shows the complete procedure of the semi-structured interview, including the opening and closing statements. The interviews took between 10 and 30 minutes to complete.

Data Analysis

This section will describe the analysis performed on both the quantitative and qualitative data. Furthermore, it will explain how both analyses were integrated to answer the research questions.

Quantitative data analysis

The quantitative data was exported from TIIM into an Excel file for analysis. TIIM generated a personal identifier number for each participant to anonymise the data. All data from the different starting groups were combined, and data from the excluded participants were removed. Next, the data was imported into Rstudio (Version 4.1.2), the integrated development environment for the R programming language. The ‘tidyverse' package was

used for data manipulation and visualisation. Three separate data sets were made for the demographic, day, and week data. The day data included the results of the daily PSS-10 questionnaire, and the week data included the information from the weekly PSS-10 and SHAI-14 questionnaires. All data sets were converted into a long format before analyses.

The data was cleaned and inspected for outliers and missing data. Afterwards, the data was transformed so that timestamps were changed to suffixes to represent each day, from day 1 to 14 (suffixes 0 to 13). The scoring of questions 4, 5, 7 and 8 of the PSS-10 were reversed according to the scoring scale. Scores for each questionnaire were summed accordingly and put into one score variable (SHAI and PSS10). Participants were excluded from the analysis if they did not fill in at least 80% of the questionnaires. The weekly PSS-10 scores were excluded from the week data. The Daily PSS-10 scores were converted to average weekly scores (avg_PSS10) and added to the week data. Descriptive statistics were calculated to provide a general overview of the results. Additionally, a simple plot of each participant's average PSS-10 score, and SHAI-14 score was made to evaluate the score change of the smartwatch's presence on the respective scores.

A linear mixed-effects model was applied to examine the smartwatch's effect on perceived stress based on the weekly average PSS-10 score and health anxiety based on the SHAI-14 score. The smartwatch's presence and smartwatch presence in week 1 was coded as a dichotomous variable (1 for present, 0 for not present). Details of the used linear mixed-effects models can be found in Appendix 5.2.

Random effects were included to account for variations between perceived stress and Health Anxiety scores of individuals. Both models assume the random effects follow a normal distribution with a mean of 0 and a variance of σ^2. This assumption was checked using diagnostic plots. The ‘lmer’ function of the ‘lmerTest’ package was used to fit the linear mixed-effects model to the data. The statistical significance of the analysis will be assessed using p-values and 95% confidence intervals. The model for perceived stress included 44 observations and the model for health anxiety included 40 observations. The complete R-code used can be found in Appendix 6.

Qualitative data analysis

All transcripts for the qualitative data analysis were uploaded to Atlas.ti web v7.7.1. (Scientific Software Development GmbH). This study performed an inductive thematic analysis with some deductive elements. This was done to let the data form its own themes but add some specificity in later steps of the analysis. This approach entails that no prior theories

or preconceptions are used to group or fit the data in analytic preconceptions. This method suits this exploratory study as it is data-driven and leaves room for all relevant information to be included in the analysis. However, it also adds some focus in later steps of the analysis. It must, however, be noted that some theoretical preconceptions of the researchers cannot be entirely ruled out (Braun & Clarke, 2006).

Both researchers coded two initial interviews conducted by the other to let no prior knowledge of the participant affect the coding; this was done using a purely inductive approach. The codes attempted to interpret the meaning of what the participants said in the interview without any theoretical preconceptions. Afterwards, both researchers compared their coded interviews and created and defined a set of codes which could be used to code the rest of the interviews; during this step, some theoretically influenced decisions were made to focus the next step in the analysis, an example being the addition of a code covering misinterpretation of bodily sensations which is relevant for the cognitive theory of health anxiety (Salkovskis et al., 2003). Furthermore, an additional "Health tracking" theme was added to summarise all comments relevant to health and health anxiety. Both researchers coded the initial four interviews and the remaining ten using this set of codes. Both researchers coded seven interviews. Any quotations that researchers were unsure of or could not code were marked as “Discuss” and accompanied by a note so that they could be reviewed with both researchers later. Quotes deemed irrelevant were marked as “Other" and excluded from the analysis.

An example of this would be repeating the question if misunderstood by either the participant or interviewer and closing statements of the interview irrelevant to the analysis. After all interviews were coded individually, the researchers discussed the quotes and sections marked under "Discuss" to resolve discrepancies, add new codes, and refine existing codes. After all discrepancies were resolved or recoded, the researchers discussed and created four main themes and six sub-themes based on the existing codes. These themes were defined, after which all existing codes were grouped under the themes for later use. The codebook for the thematic analysis can be found in Appendix 6.

Mixed-methods analyses

First, the two types of collected data were analysed independently and later integrated; this is called an independent analysis of mixed methods (Fetters, 2020). The qualitative data was compared to the quantitative data, and similarities and discrepancies

were examined. Furthermore, the qualitative data was also used to supplement and explain the effects of smartwatch presence on perceived stress and health anxiety shown by the quantitative data.. The qualitative data can shed light on the participants' usage and experiences with the smartwatch during the experimental period as reported after the whole period, which is not available by simply observing the results of the quantitative data. This allows for stronger links to be established by combining the quantitative and qualitative results (Bishop, 2015).

Furthermore, the qualitative data inquired about general opinions and feelings about using smartwatches, which can provide valuable insight for future studies. Descriptive quantitative data and qualitative data were combined in four individual accounts of participants. These participants were selected based on a score change observed from the descriptive statistics. These participants' accounts were observed, and discrepancies were discussed, giving valuable insight into individual differences.

Results

Participant flow

All participants (26) took part in the quantitative data collection phase. The exclusion criteria for starting this phase were insufficient control of the Dutch language, recent use of a smartwatch and the presence of a severe mental illness. Participants were excluded from the quantitative analysis if they filled in less than 80% of the questionnaires. The participants were invited via text or in person. The participants were all friends and family of the researchers. All participants were provided information about the study, and informed consent was obtained before participation. During the two-week quantitative data collection phase, the participants were instructed to complete daily questionnaires on their mobile phones using the TIIM application. There were three different starting groups, which all started one week after the other. The participants were allowed to choose their starting group, and if no group was preferred, they were put into one by the researchers based on logistic availability. Within the starting groups, the participants who would start with a smartwatch were selected at random.

The PSS-10 scores were excluded from the weekly data set as the TIIM software generated complications when converting these scores to workable data files. As the PSS-10 score was also inquired daily, we could rely on weekly averages of the daily PSS-10 scores.

Four participants were excluded from the quantitative data analysis, two did not fill in the required number of questionnaires (80%), and two later revealed that they had worn a smartwatch regularly. A complete overview of the participants included in the quantitative data analysis and the corresponding demographic information can be found in Table 1. Additionally, not all participants were included in the analysis of both linear mixed models. Two additional participants were excluded from the linear mixed model estimating the effect of smartwatch presence on the SHAI-14 score as these participants only completed one of the two measures of the SHAI-14. 44 observations were included in the perceived stress model, and 40 observations in the health anxiety model.

A subset of the participants from the quantitative data collection phase were invited to participate in the qualitative interviews. Sixteen participants were interviewed in this phase. Two participants were excluded after completing the interview and revealing that they had worn a smartwatch regularly in recent months. The qualitative semi-structured interviews were conducted in person or online and recorded for later use in the qualitative data analysis.

A complete overview of the participants included in the qualitative data analysis and the corresponding demographic information can be found in Table 1.

Table 1

Demographic Characteristics of Participants in both quantitative and qualitative data collection

Characteristic	Quantitative		Qualitative	
	n	%	n	%
Gender				
Male	22	86.4	12	75.0
Female	4	15.4	4	25.0
Non-Binary	0	0.0	0	0.0
Age (mean ± SD)	25.9 ±10.00		24.9 ± 9.3.	
Occupational Status				
Student (not working)	6	23.1	4	25.0
Student (working)	8	30.8	5	31.2
Full-time working	8	30.8	4	25.0
Unemployed	1	3.8	0	0.0
Other	3	11.5	3	18.8

Note. This table displays the demographic information of both the quantitative and qualitative participant groups. Not all participants from the quantitative group participated in the qualitative group.

Quantitative Results

Table 2 shows the descriptive statistics of the variables PSS-10 score and SHAI-14 score. The categorical variables are excluded from this table as they are either 1 or 0.

Table 2

Descriptive statistics of average PSS-10 scores and SHAI-14 scores

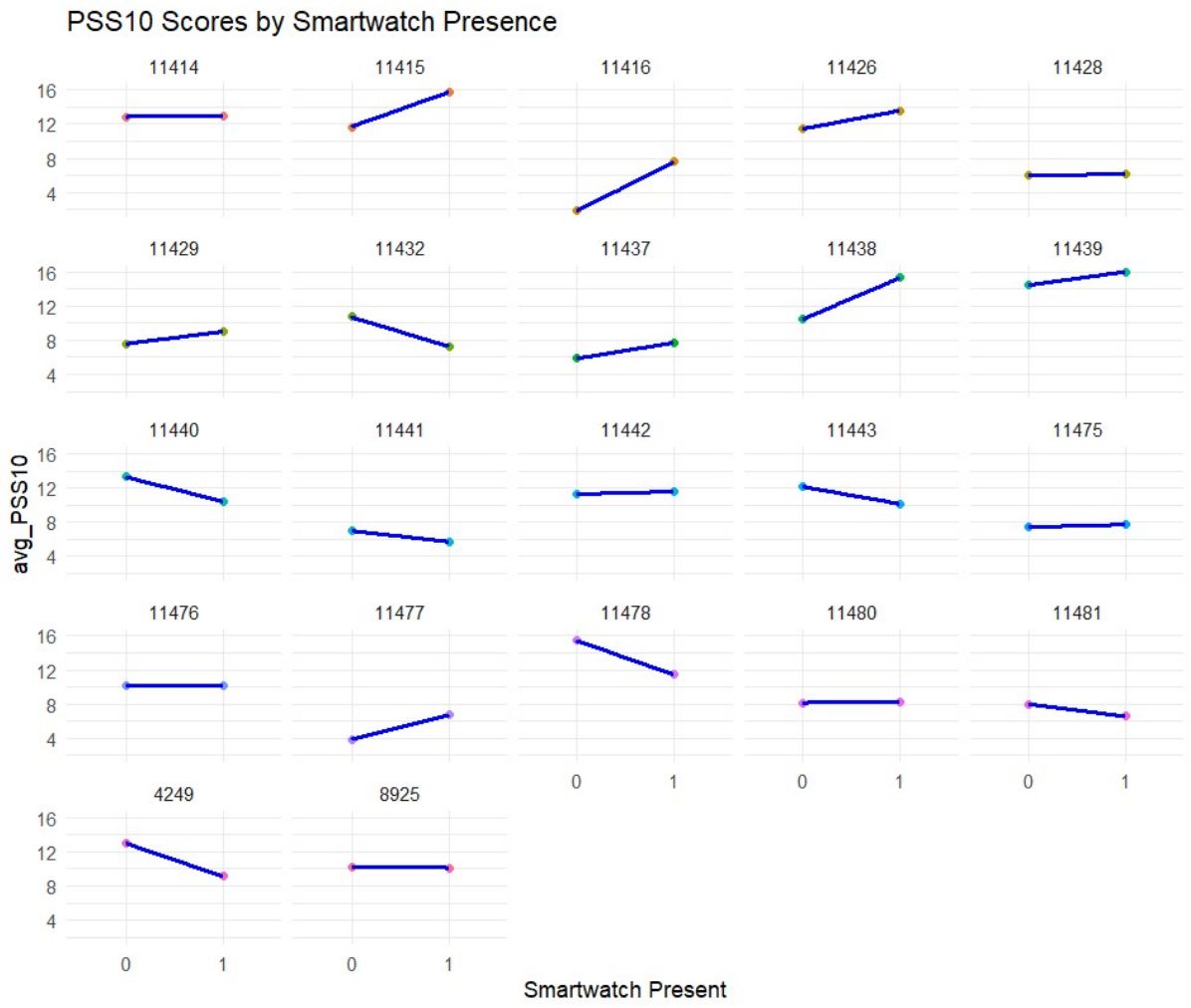
	Min	Max	Mean	SD
avg_PSS-10 score	1.857	16.00	9.82	3.27
SHAI-14 score	3.00	19.00	9.50	4.12

Note. This table displays the descriptive statistics of the PSS-10 and SHAI-14 scores, representing perceived stress and health anxiety, respectively. It used the weekly average scores of 22 participants for the PSS-10 and the weekly scores of 20 participants for the SHAI-14.

Additionally, each participant's average score on the PSS-10 and the score on the SHAI were plotted by Smartwatch Present to determine the effect of smartwatch presence on each participants score seen in Figure 3 and 4.

Figure 3

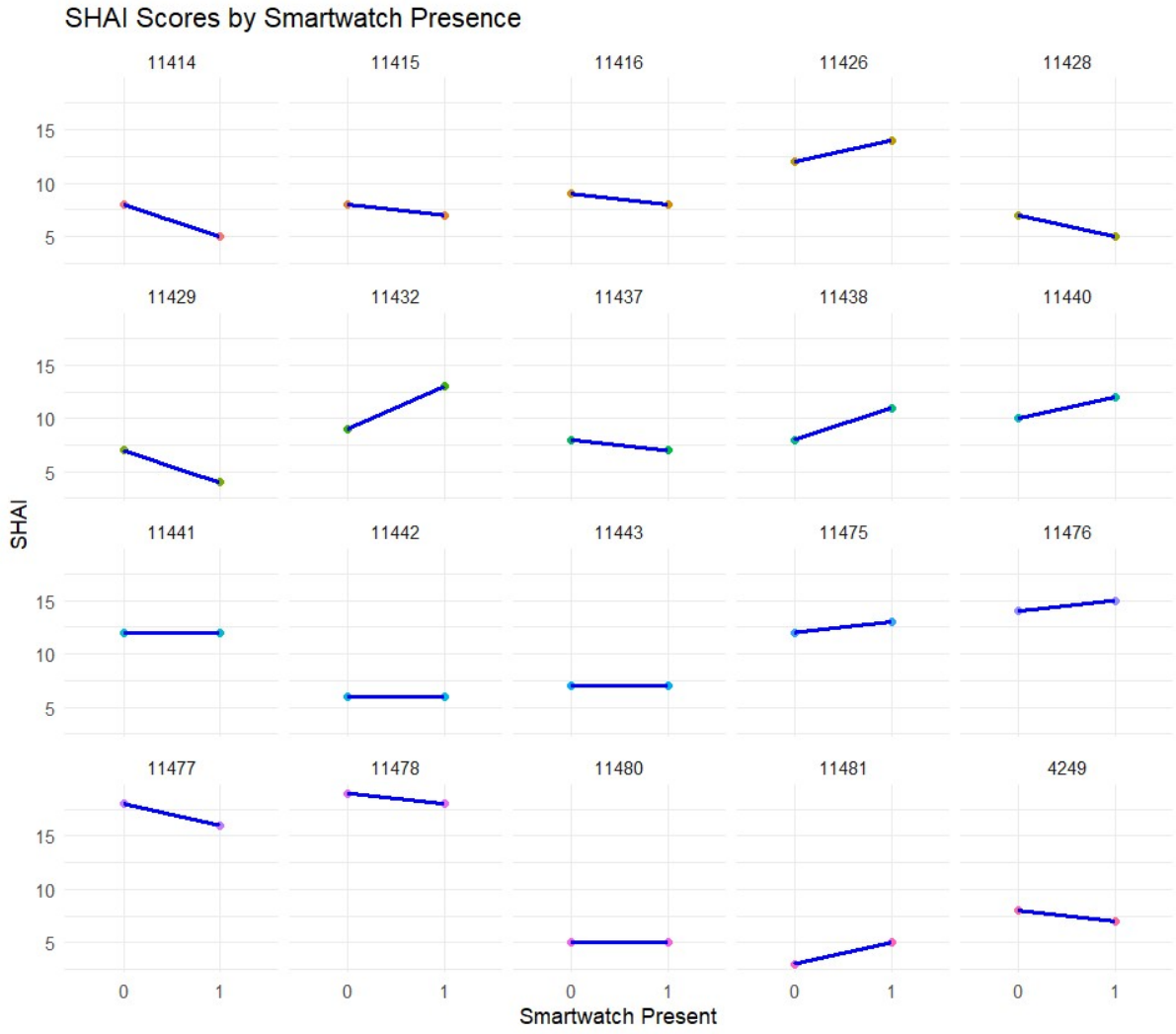
Average PSS-10 scores by Smartwatch Presence for each participant.



Note. This figure displays the average PSS-10 score for each participant when the smartwatch was not present (0) and was present (1).

Figure 4

Average SHAI scores by Smartwatch Presence for each participant.



Note. This figure displays the SHAI score for each participant when the smartwatch was not present (0) and was present (1).

These figures clearly show some significant differences between participants. These will be further explored in the mixed methods results section.

Perceived Stress. A linear mixed effects model was fitted to determine the effect of smartwatch presence on perceived stress, the detailed results of the model are shown in Table 3. The analysis revealed that the presence of a smartwatch had no significant effect on the average PSS-10 scores ($\beta = 0.297$, $p = 0.608$). Similarly, wearing the smartwatch in week 1 did not significantly influence perceived tress levels ($\beta = -0.560$, $p = 0.709$). 68.5% of the variance in the average PSS-10 score can be attributed to participants' individual differences.

Table 3

Results of the Linear mixed model estimating the effect of smartwatch presence on average perceived stress

	Average PSS-10 Score					
Predictors	*Estimates*	*std. Error*	*CI*	*t*	*p*	*df*
(Intercept)	10.078	1.293	[7.395, 12.760]	7.791	<0.001	22.039
smartwatch present	0.297	0.570	[-0.888, 1.483]	0.521	0.608	21
week1 present	-0.560	1.479	[-3.643, 2.523]	-0.379	0.709	20
Random Effects						
σ^2	3.574					
Participant	7.763					
ICC	0.685					
$N_{participant}$	22					
Observations	44					

Note: Smartwatch present is codes as 0 = not present or 1 = present. Week1 present is coded as 0 = not present in week 1 or 1 = present in week 1.

Health Anxiety. The analysis of the linear mixed effects model of smartwatch presence on health anxiety found no significant effect of smartwatch presence on the SHAI-14 score with an intercept of practically 0 (p = 1.0). Neither was there a significant effect of smartwatch presence in week 1 on the SHAI-14 score (β = 1.73, p = 0.423). A significant amount of the variance between the scores (89.6%) can be attributed to individual differences. A more detailed display of the results is found in Table 4.

Table 4

Results of the Linear mixed model estimating the effect of smartwatch presence on Health anxiety

	SHAI-14 Score					
Predictors	*Estimates*	*std. Error*	*CI*	*t*	*p*	*df*
(Intercept)	8.20	1.845	[4.325, 12.075]	4.44	**<0.001**	18.49
smartwatch present	-1.584e-16	0.429	[-0.898, 0.898]	0.00	1.000	19.00
week1 present	1.73	2.12	[-2.709, 6.175]	0.819	0.423	18.00
Random Effects						
σ^2	1.84					
Participant	15.87					
ICC	0.896					
$N_{Participant}$	20					
Observations	40					

Note: Smartwatch present is codes as 0 = not present or 1 = present. Week1 present is coded as 0 = not present in week 1 or 1 = present in week 1.

Having analysed the quantitative data, it is evident that there is no significant effect of smartwatch presence on either perceived stress or health anxiety. However, to gain insight into possible explanations for why there is no significant effect, we turn to the qualitative results for a more in-depth view.

Qualitative Results

The thematic analysis highlighted three main themes and six sub-themes essential to understanding the participant's experience with the smartwatch during the experimental period. The three main themes were i) Insight, ii) Adjustments, and iii) Attitudes towards smartwatches. An additional theme regarding health tracking was added; this was done to encompass all relevant information related to health anxiety. As the interviews were in Dutch, all quotations were translated from Dutch to English and interpreted accordingly.

Insight

The theme Insight referred to the usage of real-time data to gain insight into their (bodily) experiences and activities. The three subthemes identified for insight were i) Physiological insight, ii) Alignment and iii) Behavioural insight.

Physiological insight. The sub-theme of physiological insight is defined as "insights into the bodily reactions within daily routines." Participants used the smartwatch to understand how their bodies responded in various situations and were curious about how their daily routines compared to others. There was a specific interest in stress (12/14), sleep (8/14), and heart rate (13/14). This physiological insight was new to participants, and nine noted its potential to improve their lives. However, participants expressed confusion over certain measurements like HRV, Ox, and respiration, as they were unclear about what these readings meant. Some also found the numerical representation of stress levels to be vague, not knowing if their stress levels were high or low. One participant expressed specifically how the numerical representation of stress was strange to them.

"The smartwatch, of course, indicates a stress level as a number, but yeah, what that number exactly means, that's still vague for me. So, if I had a certain stress level, I didn't necessarily know if it was high or low." (Participant #11414)

This theme shows that while the smartwatch provided valuable real-time data, it also caused confusion about the meaning of this data. A more detailed description of this theme is found in Appendix 7.1.

Alignment. The sub-theme Alignment is defined as "Users assessing whether their inner sensations align with the real-time data collected by the smartwatch". This theme encompasses the common testing of the smartwatch. Almost all (11/14) participants were

interested to see if the smartwatch would reflect their personal experience in the measurements and they would compare their personal experiences with the readings. Often, participants expressed how this could confirm their experience and thought this was "pleasant". A participant expressed this by saying:

"Yeah, I personally found that nice. I could see that, yes, this day was fine, I could feel that myself. And I see here that my stress level was indeed low, so yeah, that matches." (Participant #11440)

However, 12 participants considered their own experiences the standard, and if not reflected by the smartwatch they would doubt its accuracy. Two participants did this differently; they considered the smartwatch to be the standard and would assess if their personal experience was accurate based on the smartwatch. One participant expressed this as follows:

"At least, by getting that confirmation again, I also have the confirmation for myself that how I experience my stressors actually corresponds to reality." (Participant #11477)

Assessing whether the smartwatch would align with their personal experiences was common among participants. Most participants considered their personal experiences as the standard, and if the smartwatch did not align, they doubted its accuracy. However, two participants did this differently as they assessed the accuracy of their personal experience through the feedback of the smartwatch.

Behavioural insight. This theme is defined as "Insights participants gained into their activity patterns within daily routines". It encompasses what participants looked at regarding their physical activities, how they compared them to the norm, and how they feel about them. Overall, participants were positive about this insight; some (6/14) could even use it to improve their abilities. Only one participant expressed specific indifference to the physical activity feedback by saying:

"No, yeah, I see it, and then I think, yeah, seven thousand steps taken, and I think, "OK". Not that I become very happy because of that or anything." (Participant #11426)

Adjustments

The theme Adjustments is defined as Any changes in behavioural patterns or cognitive schemata resulting from smartwatch's feedback. It looks at possible changes in

cognitive schemata or intentions to change behaviour. Nine participants changed their cognitive schemata, behavioural patterns, or both, but these changes did not persist post-use. One participant made a behavioural change to adapt to stressful situations by identifying stressful moments and responding more calmly:

"Sometimes a (I am a) bit stressed that I sometimes thought like take a step back, taking back rest and doing slightly less stressful things. (...) When I'm stressed, but don't panic, for example like oh I still have to get this, I still have to get that. Then doing that a bit calmer. Hopefully I will then forget a little less. Usually, I have to walk back three times to get my things and now twice." (Participant #11438)

This behavioural change was accompanied with a change in cognitive schemata as the participant's perception of stress changed. Other participants mentioned similar effects; they felt motivated to change their behaviour or had a heightened awareness of their actions on their health. Six participants expressed a change in their perceived stress of which four participants mentioned how their perceived stress had decreased. One used feedback at the moment to reduce their stress, while three reflected on their stressful situations to handle future stressful situations better.

However, two participants expressed increased stress due to the smartwatch. One participant mentioned that the stress feedback during stressful situations would prolong and increase their stress when it would otherwise pass by itself:

"I just sometimes feel in those moments, when it indicates that you have a very high stress level. Then I think that, because it indicates it so strongly, it probably just gave me more stress at the moment. While normally, maybe such a stressful moment would pass much more quickly, now it lasts a bit longer or something. (...) You already have stress, and then it's a sort of confirmation of 'Oh, damn, I have stress,' so you stress even more about it." (Participant #4249)

The other participant experienced an increase in their perceived stress when the smartwatch indicated a high-stress even though the participant did not feel stressed. However, it must be noted that both participants expressed that they experienced less stress in situations they normally deemed stressful by reviewing their stress levels in hindsight.

Although six participants expressed how the smartwatch affected their perception of stress, the largest group (8/14) did not have such an experience. They were unaffected by the stress feedback and did not change their perception of stress.

Health tracking

This theme describes the opinions and experiences of participants regarding the health-tracking functionality of the smartwatch. It explores the general opinions of health-tracking devices and their effect on health anxiety. Participants often referred to a larger scope when discussing the effects of health tracking and feedback. They reflected how this technology could be used to increase physical activity, prevent disease through early detection or help individuals to worry less about their health. However, these comments were in the context that it could benefit some people and not everyone. Thirteen participants expressed concern that individuals prone to worry or panic could be negatively affected by misinterpreting information and readings. This could lead to increased worry and false concern for one's health. One participant explained it as follows:

"But you also... I don't know, you really have to be careful about how you bring something like that to a person. And that there really has to be something alongside it. That people also get to hear that... It's not a problem to have this. Like, you're not going to die from this. So that people don't... I: Yeah. So that people don't suddenly think... Oh, I have a high reading. There must be something wrong with me. - Yeah, like oh, I need to see a doctor now." (Participant #4249)

Participants expressed how this misinterpretation or confusion could lead to increased health concerns or anxiety in more sensitive individuals. None of these doubts about were present when participants reflected on their personal experiences. Six participants felt less worried about their health and felt an increased positive awareness. They felt that health concerns were reduced as the feedback showed their concerns were unwarranted.

One participant explained how they experienced moments of anxiety or panic with regards to their health. In these situations, they checked their smartwatch for confirmation, but did not experience a comforting effect. This specific case will be further explored in the mixed results section.

This theme shows differing opinions about the effects of a smartwatch on individuals' perceptions of health. Participants reflect on how it can benefit some but not others. The specific account of one participant highlights a potential health anxiety reducing effect, further explored in the mixed results section.

Attitudes towards smartwatches

The main theme, Attitudes towards smartwatches, is defined as “Any opinions that users have regarding smartwatches and their impact.” The three sub-themes identified are i) Experience vs. Measurement, ii) Accuracy of Measurement and iii) Consideration Impacts of Use.

Prioritising Experience vs. Measurement. The sub-theme Experience vs. Measurement is defined as "The extent to which users value real-time data to describe their real-time experiences". This theme describes a substantial difference between two participants in how they feel the real-time data relates to their personal experiences.

One participant expressed how the data had nothing to say about them and how their own experience is the only thing they considered, expressed as follows:

"While I think, yeah, it's just a measurement. You can't always rely on it, in the sense that the device can tell me if I've slept well, but if I wake up and I'm not rested, then I'm not rested. The device can say whatever it wants”. (Participant #11429)

Conversely, another participant expressed that they used the smartwatch to identify their feelings, especially stress. They usually did not recognise stress and while wearing the smartwatch, they constantly checked to see exactly what they felt. This gave the participants a better understanding of what stress was, which they expressed as follows:

"If I feel stressed, I now better understand the difference between not being stressed and being stressed. It's a bit like when you drink coffee and suddenly realise, 'Oh yeah, this is what it feels like when you've had too much caffeine.' Just a bit of bouncing around, I have that with stress as well. So, it has made me think that I can put labels on it so that, for example, at high stress, you're now at 25 or so, which is what I also felt."
(Participant #11477)

Additionally, with regards to stress, three participants mentioned that their personal experience did not align with their readings, which led to confusion. These participants started to doubt their own abilities to read and recognise their feelings.

This sub-theme shows differences in how individuals relate smartwatch data to their experiences and how this can sometimes lead to doubt. The contrast between one participant who disregarded the data and another who relied on it highlights the variation in this sample.

Accuracy of Measurement. The sub-theme Accuracy of Measurements is defined as "The extent to which users trust the accuracy of the smartwatch's measurements." It covers all opinions from participants regarding the perceived accuracy of the smartwatch. Almost all (13/14) participants mentioned their perceived the accuracy of the smartwatch. Participants considered some measurements accurate (n = 27), with mentions of stress, heart rate and sleep.

Doubts about the accuracy were expressed most often (n = 30) and except for one were all related to stress. Ten participants mentioned perceived inaccuracies of the smartwatch (n = 21) and were most often related to stress (n = 13). The doubts and inaccuracies were all related to instances when the smartwatch did not align with the participants personal experiences. This led to some participants viewing the feedback as irrelevant:

"I didn't really see it as structural feedback, or anything like that. Or as accurate feedback. For example, my stress levels were just through the roof every day, while it was just because I was exercising every day. So yeah, I thought, well, for me it didn't seem right, so yeah, then you don't do much with feedback." (Participant #11440)

Overall, opinions about the accuracy of the measurements vary between and within participants. Stress measurements were the most discussed, with a stronger doubt than trust in their accuracy. Discrepancies between personal experiences and measurements led to doubts of perceived accuracy, showing how this is an important factor for trusting in feedback. A more detailed description of this theme can be found in Appendix 7.2.

Considerations Impacts of Use. The sub-theme Considerations Impacts of Use is defined as the User's beliefs regarding the impact of smartwatches on individual and societal levels. Most participants (11/14) had positive experiences with the smartwatch. Participants enjoyed the insights into their activities and health, and some felt more motivated to be more active. There were however some general critiques of the smartwatch, including skin

irritation, operational issues, high purchase price, how it could be distracting, and privacy concerns regarding personal data. The most prominent concern mentioned by seven participants, was the potential for individuals to become obsessed with the data. Explained by one participant:

"And, I think for others, but for other people, it can actually go in the wrong direction. And then I'm thinking of someone who has a strong need for control, you know, that they might get too caught up in it. I personally believe that that's never good." (Participant #11441)

While participants saw personal and potential societal benefits, they also considered a range of negative impacts with a particular risk of obsession. A more detailed description of this theme can be found in Appendix 7.3.

Mixed Methods Results

This section integrated the quantitative and qualitative results to compare and review the similarities and differences between the two data types. It was apparent from the quantitative analysis that the presence of a smartwatch had no significant effect on perceived stress or health anxiety. However, the qualitative interviews found some significant differences between participant accounts. This section will examine the absence of a significant effect within the sample, comparing the quantitative and qualitative results on a group level and highlight participants based on the score change from Figures 3 and 4 of the quantitative data.

Effect of Smartwatch Presence on Perceived Stress

The quantitative data found no significant effect for smartwatch presence or present in week 1 for the sample. Qualitative interviews reflected this, with the largest group of participants (8/14) reporting no change in their perception of stress. However, some participants did experience a change in perceived stress. Two participants' accounts selected based on Figure 3 are explored in detail.

Participant #4249 had a mixed experience with the smartwatch and their perceived stress. In the qualitative interviews, they reported increased stress in certain situations and explained that receiving stress feedback during stressful situations prolonged and intensified their stress, which would otherwise subside more quickly. Despite this increase they also

experienced a decrease in perceived stress about work, which they considered highly stressful. The smartwatch feedback showing low stress levels reduced their perceived stress:

"But also, the other way around. For example, at work, I always had super-low stress levels. So maybe before, I sometimes dreaded going to work. But now, knowing that it causes me so little stress, I worry about it less. I think, oh well, it'll be fine." (Participant #4249)

The score change showed that participant #4249's average perceived stress score was lower when wearing the smartwatch, suggesting that regardless of stress-inducing moments, there was a net decrease on their overall perceived stress.

Participant #11416 similarly had a two-sided experience. They doubted the accuracy of stress measurements and felt it did not reflect their personal experience. However, the participant mentioned how they had an increased awareness of their stress and subsequent behavioural changes:

"I think it's mainly that I've become more aware. Seeing the stress meter or whatever makes me more conscious of when I'm stressed. (...) It's not so much that I can better assess how and what causes stress, but rather that I'm more aware that if there's stress, I need to reduce it." (Participant #11416)

The score change showed an increase in their perceived stress. Which can be attributed to their heightened awareness initially increasing their stress response.

While the overall quantitative data showed no significant effect of smartwatch presence on perceived stress, these individual accounts highlight the importance of individual and situational differences when evaluating the impact of smartwatch presence on perceived stress.

Effect of Smartwatch Presence on Health Anxiety

No significant effect was found for smartwatch presence or smartwatch presence in week 1 on the SHAI-14. The qualitative data supported this result with only ten mentions of decreased effects on health anxiety and 40 mentions of unaffected health anxiety.

However, some individual score changes from Figure 4 and accounts from the qualitative interviews hint at a possible effect. Two participants were highlighted to explore this possibility.

Participant #11477 had a lower health anxiety score when wearing the smartwatch. They expressed how they experienced moments where they catastrophized strange bodily sensations causing worry and anxiety. They described their personal experiences with the smartwatch as potentially comforting, explaining that during health anxious moments, they would check their smartwatch for confirmation. However, they felt this did not have a significantly comforting effect on them suggesting more time to get used to the watch might help:

"I think if you wear a watch long-term, with more options to see exactly what it is, that could be more calming. (...) so you know for sure that it's accurate. I wore it for a week, and I don't know for sure how accurate those readings are. I trust it, but it's still not enough time to really label the feeling you're having at that moment." (Participant #11477)

Despite this, their scores decreased, and the participant mentioned they used the smartwatch to better understand their own experiences. This suggests that they highly responsive to the smartwatch readings and highlights the potential of smartwatches to reduce health anxiety.

Participant #11426 had an increased score of health anxiety when wearing the smartwatch. In qualitative accounts, they mentioned that the smartwatch had not changed their health perception but mentioned recently focusing more on health unrelated to the smartwatch, which could explain the slightly increased levels of health anxiety:

"When I started wearing the watch, I was also just getting back into exercising more. So, you're naturally more focused on your health to make sure you get through the week in a decent way." (Participant #11426)

Overall, the quantitative and qualitative data seem to support the absence of a significant effect of smartwatch presence on perceived stress or health anxiety on a group level. However, some discrepancies exist between and within participants, with specific situations affecting perceived stress and health anxiety. The qualitative data suggests that increased stress awareness through the smartwatch can both increase and decrease perceived stress, and smartwatches have the potential to decrease health anxiety symptoms for some individuals.

Discussion

This study examined how wearable usage affects perceived stress and health anxiety in individuals. To answer this goal, participants were introduced to a wearable for one week of a two-week experimental period in which they filled in daily and weekly questionnaires to assess perceived stress and health anxiety. The findings of this study suggest that there is no significant effect of the presence of a smartwatch on perceived stress or health anxiety. Additionally, there were varied participant experiences concerning perceived stress and health anxiety without a consistent trend between participants.

Effect of smartwatch use on perceived stress.

It is clear from the quantitative results that no significant effect was found for smartwatch presence on perceived stress, supported by the qualitative analysis concluding that most participants did not experience any change in their perception of stress. This non-significant effect is in line with the umbrella meta-analysis of Ferguson et al. (2022); however, it does not support the suggested effect found in Attige and Frank (2020) and Kanstrup et al. (2018). However, seeing that assessing stress was not the main goal for both these studies, this discrepancy between findings is not necessarily surprising.

The lack of significant effect of wearables on perceived stress could be due to a lack of trust or embodiment in the measurements of the smartwatch. Embodiment in this case is when a person sees a smartwatch as an extension of themselves or their bodies (Nelson et al., 2024). It was noted from the theme alignment that twelve out of the fourteen participants saw their own experience as the standard upon which they base their experiences. This effect was well explained by the subtheme experience vs measurement, where participants felt differently about what the smartwatch had to say about them. Furthermore, it was apparent that most participants were unsure about the accuracy of the stress measurements. Approximately 62% of the mentions of measurement inaccuracy referred to the stress measurements and how participants thought they were incorrect.

Nevertheless, nine participants adjusted or changed their physical activity patterns or cognitive schemata, which is strange considering that his effect is not reflected in the results. The previously mentioned concept of embodiment could explain this phenomenon. It was observed from the interviews that participants did not relate entirely to the smartwatch. This was apparent in most participants (N = 12), who thought their personal experience was more trustworthy than the smartwatch measurements. A study by Nelson et al. (2024) concluded

that embodiment is essential to inhibiting and sustaining behaviour change. This lack of change could be attributed to the lack of embodiment experienced by the participants. This is, however, only theorised based on the qualitative interpretation of the interviews. When incorporating this in the context of perceived stress and health anxiety, a similar argument can be made. The lack of embodiment would cause a lack of effect on either of these measures. Therefore, future studies should include a measure of embodiment to account for this effect.

The qualitative analysis gave more personal insight into two participants who mentioned an increase in their perceived stress. However, these participants mentioned how their perceived stress decreased in other situations. When investigating one of these two participants in the mixed results section, it was found that despite the perceived stress-increasing experience, their overall stress score was lower when wearing the smartwatch, which suggests a stress-decreasing effect. This is a similar finding compared to a study by Smith et al. (2019), who found that integrating wearable technology in stress management interventions could effectively decrease perceived stress. Another participant who expressed being able to use the smartwatch to lower his perceived stress had an increased perceived stress score when wearing the smartwatch. It must, however, be noted that this participant mentioned increased awareness of his stress, which can cause increased stress perception.

Effect of use smartwatch on health anxiety

Our study study found no significant effect of smartwatch presence on health anxiety; a finding largely supported by the qualitative data. This aligns with a study by (Lebel et al., 2020) in who found that health anxiety rarely changes over a short period of time. It was, however, suggested in a study by Choudhury and Asan (2021) that this is possible in short periods of time highlighting a discrepancy in our results. It could be possible that the study period was too short to measure these changes.

The qualitative study of Conboy et al. (2018) found indications that m-health apps might affect health anxiety urging for additional research. This study found minor qualitative indications of a possible increase in health anxiety using wearable technology. Our study found a similar result but only in the context of others. Participants noted that it could negatively affect individuals who were already sensitive to such effects or were quick to worry. When participants considered the impact of wearables on the way they perceived their health, only positive comments were made.

The health anxiety score for participant #11426 increased when wearing the smartwatch. However, the participant attributed this increase to recent lifestyle changes unrelated to the smartwatch, indicating that an increased awareness of health can explain this score increase. Conversely another participant had a significant decrease in their health anxiety score. This participant used the smartwatch to look for reassurance or a calming effect during health anxious moments, a reassurance-seeking behaviour described by Salkovskis et al. (2003) in their cognitive behavioural model. This model suggests that this can have an increasing and decreasing effect on health anxiety. The participant noted a potential decreasing effect but needed more time to experience it themselves. The scores did decrease indicating the potential health anxiety reducing effect of the smartwatch that warrants further investigation.

Choudhury and Asan (2021) proposed that wearable devices with health feedback could increase health anxiety when misinterpreted. Several participants expressed a similar idea in our qualitative interviews and could imagine how this could negatively affect others. However, when participants expressed personal accounts of not understanding measurements, no one expressed concern or distress. This shows that, at least in our sample, there is no support for this effect. Additionally, this effect was not mentioned or covered in the interviews of individuals who experienced an increase in their scores.

Additionally, a study by McWilliams, Cox, & Enns (2003) highlights the relevance of neuroticism when considering Health anxiety and stress. They found that individuals with higher levels of neuroticism are more likely to experience higher levels of stress and health anxiety. It could, therefore, mean that the current sample has, in general, low levels of neuroticism, which could explain why no significant effect on perceived stress or health anxiety was found. This would be an interesting addition to evaluate in future research and will be further discussed in the future research section.

Implications of findings

This study found no significant effects of smartwatches on perceived stress and health anxiety. This seems to suggest that no significant effect of perceived stress and health anxiety is expected through smartwatch use. However, the qualitative interviews did highlight some potential effects. Many participants expressed how they thought the overall impact of wearable technology in the context of health would be beneficial. Participants were motivated to improve their health through physical activity and lifestyle changes. Other participants

expressed how they felt more aware of their health and considered how this could benefit others. The health-tracking features of the smartwatch were generally received as beneficial, and participants reflected on how this could be used at home and in health care for early disease detection. However, participants also highlighted that it is essential to consider how information is communicated to avoid confusion leading to a potential increase in stress and health anxiety.

Additionally, the smartwatch measurements were not all clear to the participants, leading to confusion among them. This should also be considered for future developments of wearable technology. This effect could be reduced by explaining measurements, which can be considered confusing.

One participant who expressed suffering from symptoms of health anxiety did mention how they could potentially see a decrease in their symptoms with prolonged use. They feel like the smartwatch could give comfort and confirmation when experiencing health anxiety symptoms; additionally, their scores on health anxiety already decreased when wearing the smartwatch. This knowledge can be applied in developing interventions aimed at reducing health anxiety, as our results suggest that the smartwatches' active feedback can have a calming effect.

Several participants expressed how their perception of stress had changed and how they could occasionally reduce their perceived stress. Participants could do this by checking real-time feedback and reviewing stressful situations in hindsight. This furthermore suggests a potential decreasing effect of perceived stress through smartwatch use. Overall, it seems that from the qualitative account, there is significant potential for wearables to decrease the effects of perceived stress. Future studies should explore this potential.

Overall, the study found no significant effect of smartwatch presence on perceived stress or health anxiety. However, through qualitative accounts, it seems that the participants saw the potential for a decreasing effect on both psychosocial constructs. There is much to be gained from using smartwatches and their potential effect on perceived stress and health anxiety. However, due care needs to be taken so as not to overestimate the potential adverse effects it can have. Therefore, organisations developing or using wearable technology should consider additional research into the effects of wearable technology. The section suggestion for further research will delve deeper into the potential future steps which can be taken.

Strengths and limitations

This study has some important strengths to consider. Firstly, this study used mixed methods within subject replicated counterbalanced AB design to examine the effects of smartwatch presence on perceived stress and health anxiety. To our knowledge, it is the first study that combines an experimental quantitative data collection phase supplemented with a qualitative interview to gain additional insights into the behaviours and experiences of the participants.

Furthermore, this study only included individuals with limited or no experience wearing and using a smartwatch, increasing ecological validity. Finally, this study measured participants' day-to-day experiences with limited interventions to ensure generalizability to a larger audience.

Finally, our study contained a relatively rich and varied sample for a bachelor's thesis. This sample included students, working professionals, and others ages 19 to 59.

However, there are also some significant limitations to the study that must be addressed. Firstly, it is important to note the limitations of the TIIM software. This software was used for the daily questionnaires. To start, TIIM had a timing function that was used to open the questionnaires for participants. This function did not work for all the starting groups, which resulted in not all questionnaires being opened at the same time. Additionally, the TIIM software was not able to produce the quantitative results with the module names used to specify which day the questionnaire was filled in. This led to some complications with the data analysis. An update to the TIIM software addressing these bugs would be beneficial for further research.

The reliability and validity of the questionnaires should also be questioned. Regardless of the acceptable Cronbach's alpha of the questionnaires, it is important to note that the translated versions have not officially been validated in Dutch. This lack of official translation and tested psychometric properties could mean that the questionnaires might not measure what they are supposed to measure. The Dutch interpretation of the questions can be significantly different from the English version and can, therefore, affect the outcome of the questionnaire.

Besides this, the two-week timeframe could be too small to measure significant changes in perceived stress and health anxiety. A study by Harris et al. (2023) evaluating the changes in PSS scores over time found that in shorter time periods, perceived stress is less likely to change. Additionally, a study evaluating the effect of m-health apps on anxiety

found that an effect was most common after a few weeks of use (Lecomte et al., 2020). This suggests that a longitudinal study would be more fitting for this type of research to observe effects.

Finally, a different study design would have been better suited to answer the research questions. This study used a concurrent and triangulation mixed methods within subject replicated counterbalanced AB design. In this design, the quantitative and qualitative data are collected and analysed simultaneously, which means the quantitative data cannot be used to change or adapt the qualitative questions asked during the interview. A sequential design in which quantitative data would be analysed and used to form questions for the qualitative interview would have been better suited to gain advanced insight into potential effects on participants. This design can effectively explain and contextualise the observed quantitative findings. Furthermore, it would allow the selection of specific participants who quantitatively show an effect on perceived stress or health anxiety and ask more specific questions to explain the cause of the effects (Bishop et al., 2015). This would potentially lead to a clearer view of the potential effects and how and why they occur.

Suggestions for further research

Several study designs and directions should be considered to better adapt future research designs to explore the effects of smartwatches on perceived stress and health anxiety.

Firstly, it is important to consider a different study design. A sequential exploratory design would better explore the effects of smartwatch presence on perceived stress and health anxiety. In this design, the quantitative data is analysed before the qualitative interviews. With this design, findings from the quantitative data could be better explained by asking specific questions constructed based on the quantitative data during the qualitative interview. This method allows for a deeper exploration of possible results from the quantitative data collection (Bishop, 2015).

The research design would also be improved by making this study a longitudinal study. This way, changes in behaviour and cognitive schemata can become more apparent, and the effect can become more significant. A common trend in our findings was that all participants expressed that the study and smartwatch use was too short for them to truly adapt. This lack of embodiment would most likely need more time; therefore, a longitudinal study would be a better fit. Additionally, studies found that changes in perceived stress and health anxiety would only be present after a few weeks (Harris et al., 2023; Lecomte et al.,

2020). It would also aid the study in implementing a baseline of the measured variables. This would give additional comparison points to better estimate an effect.

Furthermore, it would be essential to work with an updated TIIM software for the questionnaires, as this would reduce some of the complications experienced in this study. It would also be recommended that only validated questionnaires be used to ensure validity and reliability. However, no validated Dutch questionnaires are available to our knowledge. This would mean that new validated questionnaires need to be constructed and validated.

Secondly, it would be recommended that the sample for the study be expanded. This study used a limited sample with a final 22 participants as part of the analysis. Increasing the sample would increase the reliability of the results. Additionally, it would be good to conduct a study in which participants have varied levels of neuroticism. Individuals with higher levels of neuroticism tend to be more susceptible to changes in their perceived stress and health anxiety. This would give a better understanding of how individuals with higher susceptibility to health anxiety and perceived stress interact with wearable devices and what effect this could have on this group. Comparing a group which experiences high levels of health anxiety or perceived stress to a control group that does not would give valuable insight into the effects of wearable devices on these groups.

By addressing these suggestions, future research can provide a more comprehensive understanding of the effects of wearable devices on perceived stress and health anxiety, particularly among individuals with varying levels of susceptibility.

Conclusion

This study aimed to explore the effects of smartwatch presence on perceived stress and health anxiety. The quantitative results of the study showed no significant effect of smartwatch presence. The qualitative results data showed that few participants experienced significant changes due to smartwatch use; this was supported by a lack of trust in the accuracy of the smartwatch among participants, hinting at a low level of embodiment among participants. Despite this, some participants did make some adjustments to their behaviour and perceptions of stress; however, these changes might have been insignificant, resulting in no representation in the data. Individual accounts of the qualitative data did highlight the potential for smartwatches to influence perceived stress and health anxiety. A more longitudinal study with a sequential design could be better suited to evaluate the effect of wearables on perceived stress and health anxiety. Additionally, a sample including

individuals who are more susceptible to experiencing perceived stress and health anxiety could shed light on the potential effects on this group.

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Appendix

Appendix 1: AI statement

"During the preparation of this work, I (and my fellow authors) used Chat-gpt to translate Dutch to English but corrected by the researchers, for assistance with some R-coding complications and for to spar for general ideas. After using this tool/service, we thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome."

"During the preparation of this work, I used Grammarly to correct spelling and grammar of the writing and for an additional plagiarism check. After using this tool/service, we thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome."

Appendix 2: PSS-10 questionnaire (Dutch)

	Nooit	Bijna nooit	Soms	Regel-matig	Heel vaak
Hoe vaak bent u overstuur geweest door iets dat onverwacht gebeurde?					
Hoe vaak heeft u het gevoel gehad dat u niet in staat was de belangrijke dingen in uw leven onder controle te houden?					
Hoe vaak heeft u zich zenuwachtig en gespannen gevoeld?					
Hoe vaak heeft u zich zelfverzekerd gevoeld over uw vermogen om uw persoonlijke problemen aan te pakken?					
Hoe vaak heeft u het gevoel gehad dat de dingen u meezaten?					
Hoe vaak heeft u het gevoel gehad dat u niet opgewassen was tegen al de dingen die u moest doen?					
Hoe vaak bent u in staat geweest om irritaties in uw leven onder controle te houden?					
Hoe vaak heeft u het gevoel gehad dat u de dingen de baas bleef?					
Hoe vaak heeft u zich boos gemaakt om dingen die buiten uw controle om gebeurden?					
Hoe vaak heeft u het gevoel gehad dat de moeilijkheden zich zo hoog opstapelden dat u ze niet te boven kon komen?					

Appendix 3: SHAI-14 questionnaire (Dutch)

1. Ik maak me zorgen over mijn gezondheid
   0 Nooit
   1 Af en toe
   2 Vaak
   3 Meestal
2. Vergeleken met andere mensen van mijn leeftijd merk ik pijntjes en klachten op
   0 Minder dan de meeste andere mensen
   1 Net zoveel als de meeste andere mensen
   2 Meer dan de meeste andere mensen
   3 Altijd in mijn lichaam
3. Welke uitspraak beschrijft het beste uw bewustzijn van lichamelijke sensaties of veranderingen?
   0 Over het algemeen ben ik me niet bewust van lichamelijke sensaties of veranderingen
   1 Soms bewust
   2 Vaak bewust
   3 Voortdurend bewust
4. Ik kan het denken aan ziekte weerstaan
   0 Zonder problemen
   1 Meestal
   2 Ik probeer gedachtes aan ziekte te weerstaan, maar ben er vaak niet toe in staat
   3 Gedachten aan ziekte zijn zo sterk dat ik niet eens meer probeer ze te weerstaan
5. Ik ben bang om een ernstige ziekte te hebben
   0 Helemaal niet
   1 Soms
   2 Vaak
   3 Altijd
6. Ik heb beelden (mentale afbeeldingen) van mezelf die ziek is
   0 Nooit
   1 Af en toe
   2 Vaak
   3 Voortdurend

7. Ik heb moeite om mijn gedachten af te houden van gedachten over mijn gezondheid
   0 Nooit
   1 Soms
   2 Vaak
   3 Altijd - Niets kan mijn gedachten afhouden van gedachten over mijn gezondheid
8. Als mijn arts me vertelt dat er niets mis is, ben ik
   0 Langdurig opgelucht
   1 Eerst opgelucht maar de zorgen keren soms later terug
   2 Eerst opgelucht maar de zorgen keren altijd later terug
   3 Niet opgelucht als mijn arts me vertelt dat er niets mis is
9. Als ik over een ziekte hoor, denk ik dat ik het zelf heb
   0 Nooit
   1 Soms
   2 Vaak
   3 Altijd
10. Als ik een lichamelijke sensatie of verandering opmerk, vraag ik me af wat het betekent
   0 Zelden
   1 Vaak
   2 Altijd
   3 Als ik een lichamelijke sensatie of verandering heb, moet ik weten wat het betekent
11. Ik voel meestal dat mijn risico op het ontwikkelen van een ernstige ziekte
   0 Heel laag is
   1 Tamelijk laag is
   2 Gemiddeld is
   3 Hoog is
12. Ik denk dat ik een ernstige ziekte heb
   0 Nooit
   1 Soms
   2 Vaak
   3 Meestal
13. Als ik een onverklaarde lichamelijke sensatie opmerk, vind ik het
   0 Niet moeilijk om aan andere dingen te denken
   1 Soms moeilijk om aan andere dingen te denken

2 Vaak moeilijk om aan andere dingen te denken

3 Altijd moeilijk om aan andere dingen te denken

14. Mijn familie of vrienden zouden zeggen dat ik

0 Me niet genoeg zorgen maak over mijn gezondheid

1 Een normale houding heb ten opzichte van mijn gezondheid

2 Me te veel zorgen maak over mijn gezondheid

3 Een hypochonder (iemand die zich veel zorgen maakt om zijn of haar gezondheid) ben

Appendix 4: Qualitative Interview Overview

Semi-structured interview (Dutch)

Vooraf: Bedankt dat je mee wil werken aan dit interview. Het doel van dit interview is om diepere inzichten te krijgen in jouw ervaringen van deelname aan onze studie. Dit interview zal waarschijnlijk een half uurtje duren. Er worden geluidsopnamen gemaakt van dit interview die wij gaan gebruiken voor transcriberen en coderen voor de analyse. Ga je akkoord met deelname aan en het opnemen van dit interview?

- *Hoe ervaarde je het dragen van een smartwatch?*
    - Hoe ervaarde je het gebruik van de smartwatch? Zou je er bijvoorbeeld zelf een gaan kopen?
- *Merkte je een verandering in je gedrag in de eerste paar dagen?*
    - Zo ja: Kan je daar een voorbeeld van geven?
    - Zo nee: Kan je omschrijven hoe je met de smartwatch omging in de eerste paar dagen?
    - Hoe heb je deze verandering(en) ervaren?
    - Zijn er dingen die je sinds het dragen van de smartwatch anders bent gaan doen?
- *Hoe ervaarde je het krijgen van feedback van de smartwatch?*
    - [**Stress feedback niet genoemd**]: Hoe ervaarde je het krijgen stress feedback?
    - [**Stress Appraisals**] Heb je het gevoel dat je je stress anders bent gaan inschatten sinds het dragen van de smartwatch?
        - Zo ja/nee, kan je daar wat meer over vertellen?

- [**Stress Appraisals**] *Heb je het gevoel dat je meer vertrouwen hebt gekregen dat je verwachte dagelijkse stressoren beter aankan? (Voorbeelden dagelijkse stressoren: deadlines, haast hebben, belangrijke afspraak of andere verplichtingen).*
    - Zo ja/nee, kan je daar wat meer over vertellen?
- [**Health Anxiety**] Hoe kijk je naar je eigen gezondheid sinds het dragen van de smartwatch?
- [**Health Anxiety**] Wat vond je van de smartwatch zijn metingen (hartslag, HRV, respiration, OX, slaap etc.) wat betreft gezondheid?
    - Vraag door over metingen die de deelnemer niet benoemd of niet goed kent/vaag vindt.
- **[Health Anxiety]** Ben je je meer zorgen gaan maken over je gezondheid sinds het dragen van de smartwatch?
- Zo ja: kan je vertellen hoe?
- [**Health Anxiety**] Hoe voel jij je/hoe denk jij over het toenemende gebruik van smartwatches om gezondheid in de gaten te houden?
- Zijn er volgens jou voor en na delen van het gebruik van smartwatches voor gezondheid?
- **[Eind vraag]** Heb je nog ervaringen gehad tijdens jouw deelname die wij tot nu toe niet hebben besproken maar die je wel zou willen delen?

Achteraf: Bedankt voor je deelname aan dit interview en onze studie. Als je het leuk vindt kan ik je een rapport sturen met jouw persoonlijke resultaten en een verslag van de gehele studie.

Semi-structured interview (English)

Before:

Thank you for agreeing to participate in this interview. The aim of this interview is to gain deeper insights into your experiences participating in our study. This interview will likely take about half an hour. Audio recordings of this interview will be made, which we will use for transcribing and coding for analysis. Do you agree to participate in and have this interview recorded?

- **How did you experience wearing a smartwatch?**

    - How did you experience using the smartwatch? For example, would you consider buying one yourself?

- **Did you notice a change in your behavior in the first few days?**
    - If yes: Can you give an example of that?
    - If no: Can you describe how you handled the smartwatch in the first few days?
    - How did you experience these changes?
    - Are there things you have started doing differently since wearing the smartwatch?
- **How did you experience receiving feedback from the smartwatch?**
    - [Stress feedback not mentioned]: How did you experience receiving stress feedback?
    - [Stress Appraisals] Do you feel that you have started to assess your stress differently since wearing the smartwatch?
        - If yes/no, can you elaborate on that?
- **[Stress Appraisals] Do you feel that you have gained more confidence in your ability to handle your expected daily stressors better?** (Examples of daily stressors: deadlines, being in a hurry, important appointments, or other obligations).
    - If yes/no, can you elaborate on that?
- **[Health Anxiety] How do you view your own health since wearing the smartwatch?**
    - What did you think of the smartwatch's measurements (heart rate, HRV, respiration, OX, sleep, etc.) regarding health?
        - Follow up on measurements that the participant did not mention or found unclear/vague.
- **[Health Anxiety] Have you become more worried about your health since wearing the smartwatch?**
    - If yes: Can you explain how?

- **[Health Anxiety] How do you feel/think about the increasing use of smartwatches to monitor health?**
    - Do you see any pros and cons of using smartwatches for health?
- **[Final question] Have you had any experiences during your participation that we have not discussed yet but that you would like to share?**

After:

Thank you for participating in this interview and our study. If you're interested, I can send you a report with your personal results and a summary of the entire study.

Appendix 5: Supplementary methods

Appendix 5.1: participant instructions

To start participation in any starting group of the quantitative data collection, the participants were instructed to install the TIIM app and fill in the participation code they received from the researchers. After being added to the correct intervention, participants could fill out the informed consent form and provide their demographic information (Age, gender, and occupational status). Furthermore, participants were instructed to turn on notifications for the TIIM application to receive notifications. Participants were instructed to do this before their participation on day 1. On day 0, the participant group who received a smartwatch were personally visited by the researcher to get a short demonstration on how to operate the smartwatch. Participants receiving a smartwatch in their second week received the same in-person instruction.

Appendix 5.2: Linear mixed-effects models

The linear mixed-effects model for the effect of smartwatch presence on weekly average perceived stress is specified as:

$$avg\_PSS10_{ij} = \beta_0 + \beta_1 \times week1\_present_j + \beta_2 \times smartwatch\_present_i + participant_i + e_i$$
$$e_i \sim N(0, \sigma^2)$$
$$participant_i \sim N(0, \sigma 2)$$

avg_PSS10_i represents the weekly average perceived stress score for participant i, β_0 represents the fixed intercept, $participant_i$ represents the random effect of individual differences in avg_PSS-10 scores. β_1 is the fixed effect coefficient for the presence of a smartwatch in week 1 ($week1\_present_i$), a dichotomous variable coded as 1 if the smartwatch was worn in week 1 and 0 if otherwise. Furthermore, β_2 represents the fixed effect coefficient

of smartwatch presence (smartwatch_ present$_i$) and is a dichotomous variable indicating whether participant *i* had a smartwatch present with (1 if yes, 0 if no).

The linear mixed-effects model for the effect of smartwatch presence on Health Anxiety is specified as:

$$shai\_score_i = \beta_0 + \beta_1 \times week1\_present_j + \beta_2 \times smartwatch\_present_i + participant_i + e_i$$
$$e_i \sim N(0, \sigma^2)$$
$$participant_i \sim N(0, \sigma 2)$$

Where shai_score$_i$ represents the health anxiety score for participant i. β_0 represents the fixed intercept, participant$_i$ represents the random effect of individual differences in Shai_score. β_1 is the fixed effect coefficient for the presence of a smartwatch in week 1 (week1_present$_i$), a dichotomous variable coded as 1 if the smartwatch was worn in week 1 and 0 if otherwise. Furthermore, β_2 represents the fixed effect coefficient of smartwatch presence (smartwatch_ present$_i$) and is a dichotomous variable indicating whether participant *i* had a smartwatch present (1 if yes, 0 if no).

Appendix 6: R-code for data analysis

```
library(tidyverse)


# dataframes inladen
day_data <- readRDS("df_day_data_analysis_2.rds")


week_data <- readRDS("df_week_data_analysis_2.rds")
# PSS-10
# Calculate average PSS-10 score per week per participant
week_avg <- day_data %>%
  filter(!is.na(PSS10)) %>%  # Remove rows with missing PSS-10 scores
  mutate(suffix = ifelse(suffix <= 6, 0, 1)) %>%  # Assign week 1 for days 0-6 and week 2 for days 7-13
  group_by(ID.Number, suffix) %>%
  summarise(avg_PSS10 = mean(PSS10, na.rm = TRUE), .groups = 'drop')


# Merge the weekly average PSS-10 scores with week_data
week_data <- week_data %>%
```

```
  full_join(week_avg, by = c("ID.Number", "suffix"))

week_data$smartwatch_present[week_data$ID.Number == "11439" &
is.na(week_data$smartwatch_present)] <- 1

week_data$smartwatch_present[week_data$ID.Number == "8925" &
is.na(week_data$smartwatch_present)] <- 0

# linear mixed model PSS10
library(lmerTest)
library(modelr)

week_data %>%
  summary()

week_data %>%
  lmer(avg_PSS10 ~ smartwatch_present + (1 | ID.Number) + week1_present, data = .) %>%
  summary()

# specifieke dataset SHAI
week_data_SHAI <- week_data[-c(19,20,43,44), ]

# linear mixed model SHAI
week_data_SHAI %>%
  lmer(SHAI ~ smartwatch_present + (1|ID.Number) + week1_present, data = .) %>%
  summary()

modelSHAI <- week_data_SHAI %>%
  lmer(SHAI ~ smartwatch_present + (1|ID.Number) + week1_present, data = .)

week_data %>%
  add_predictions(modelSHAI) %>%
```

```
  add_residuals(modelSHAI) %>%
  ggplot(aes(x = pred, y = resid)) +
  geom_point()

week_data %>%
  ggplot(aes(x = factor(smartwatch_present), y = SHAI)) +
  geom_boxplot() +
  labs(x = "Smartwatch_present", y = "SHAI-14")

# Load necessary library
library(dplyr)

# Create the plot with facets for each participant and additional customizations
ggplot(week_data, aes(x = smartwatch_present, y = avg_PSS10, group = ID.Number)) +
  geom_point(aes(color = factor(ID.Number))) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  facet_wrap(~ ID.Number, ncol = 5) +
  labs(title = "PSS10 Scores by Smartwatch Presence",
       x = "Smartwatch Present",
       y = "avg_PSS10",
       color = "Participant ID") +
  theme_minimal() +
  theme(legend.position = "none")  # Hides the legend for Participant ID
geom_smooth() using formula = 'y ~ x'

# SHAI
ggplot(week_data_SHAI, aes(x = smartwatch_present, y = SHAI, group = ID.Number)) +
  geom_point(aes(color = factor(ID.Number))) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  facet_wrap(~ ID.Number, ncol = 5) +
  labs(title = "SHAI Scores by Smartwatch Presence",
```

```
      x = "Smartwatch Present",
      y = "SHAI",
      color = "Participant ID") +
  theme_minimal() +
  theme(legend.position = "none")  # Hides the legend for Participant ID
geom_smooth() using formula = 'y ~ x'
```

Appendix 7: Thematic analysis codebook

code name	comment	Aanpassingen	Inzicht lichaam	Toetsen ervaringen	Inzicht activiteiten	Beleving vs. Meting	accuraatheid metingen	Afweging impact gebruik
wel aanpassing	heeft een deelnemer zich aangepast tijdens of na het dragen v	Aanpassingen						
geen aanpassing	deelnemer heeft geen aanpassingen gedaan tijdens het drage	Aanpassingen						
Inaccuraat metingen	Deelnemer dacht dat de meting van de smartwatch niet accur	Afweging impact gebruik	Accuraatheid metingen	Beleving vs. Meting	Aanpassingen	Inzicht lichaam	Inzicht activiteiten	Toetsen ervaringen
twijfel accuraatheid metingen	de deelnemer twijfelt aan de accuraatheid van de metingen	Accuraatheid metingen	Afweging impact gebruik					
accuraat metingen	de deelnemer denkt dat de metingen accuraat zijn	Accuraatheid metingen	Afweging impact gebruik	Beleving vs. Meting	Toetsen ervaringen	Aanpassingen	Inzicht lichaam	Inzicht activiteiten
negatief over feedback	De deelnemer had negatieve ervaring met de meldingen van c	Accuraatheid metingen	Afweging impact gebruik	Inzicht lichaam	Aanpassingen	Beleving vs. Meting	Toetsen ervaringen	Inzicht activiteiten
positief over feedback	De deelnemer had positieve ervaringen met de meldingen van	Inzicht activiteiten	Toetsen ervaringen	Beleving vs. Meting	Inzicht lichaam	Aanpassingen	Accuraatheid metingen	Afweging impact gebruik
omstandigheden	dit omvat alle omstandigheden van de deelnemer en de mening van de deelnemer over het onderzoek							
lichamelijke twijfel	de deelnemer twijfelt aan hun eigen herkenning van lichamelij	Aanpassingen	Toetsen ervaringen	Beleving vs. Meting	Inzicht lichaam			
kritiek holistisch positief	deelnemer benoemt voordelen van smartwatch die niet te ma	Beleving vs. Meting	Inzicht activiteiten	Aanpassingen	Toetsen ervaringen	Inzicht lichaam	Afweging impact gebruik	
kritiek holistisch negatief	deelnemer benoemt nadelen van smartwatch die niet te mak	Accuraatheid metingen	Inzicht activiteiten	Toetsen ervaringen	Afweging impact gebruik	Beleving vs. Meting	Aanpassingen	Inzicht lichaam
kritiek fysiek positief	deelnemer benoemt voordelen van smartwatch die te maken	Afweging impact gebruik	Beleving vs. Meting					
kritiek fysiek negatief	deelnemer benoemt nadelen van smartwatch die te maken h	Beleving vs. Meting	Afweging impact gebruik					
interessante functies	de functies die de deelnemer interessant vond	Inzicht lichaam	Inzicht activiteiten	Toetsen ervaringen				
oninteressante functies	de functies die de deelnemer niet interessant vond	Inzicht activiteiten	Toetsen ervaringen	Beleving vs. Meting	Afweging impact gebruik	Inzicht lichaam	Accuraatheid metingen	Aanpassingen
intent voor gebruik	waarom de deelnemer de smartwatch of functie gebruikt	Inzicht lichaam	Toetsen ervaringen	Aanpassingen	Inzicht activiteiten	Afweging impact gebruik		
verhoogde eisen stressoren		Aanpassingen	Beleving vs. Meting	Accuraatheid metingen	Inzicht lichaam	Toetsen ervaringen		
verlaagde eisen stressoren		Aanpassingen	Afweging impact gebruik	Beleving vs. Meting	Inzicht activiteiten	Toetsen ervaringen	Accuraatheid metingen	
onveranderde eisen stressoren		Toetsen ervaringen	Beleving vs. Meting	Accuraatheid metingen	Aanpassingen	Inzicht activiteiten		
verhoogde capaciteiten		Aanpassingen	Afweging impact gebruik	Inzicht lichaam	Beleving vs. Meting	Toetsen ervaringen		
verlaagde capaciteiten		Beleving vs. Meting	Aanpassingen	Inzicht lichaam	Toetsen ervaringen	Afweging impact gebruik		
onveranderde capaciteiten		Aanpassingen	Inzicht lichaam	Beleving vs. Meting	Toetsen ervaringen	Accuraatheid metingen		
voor gebruik smartwatch gezondheid		Afweging impact gebruik	Inzicht activiteiten	Inzicht lichaam				
tegen gebruik smartwatch gezondhei		Afweging impact gebruik	Beleving vs. Meting	Inzicht activiteiten	Inzicht lichaam			
verlaagde health anxiety		Aanpassingen	Beleving vs. Meting	Inzicht lichaam	Inzicht activiteiten	Toetsen ervaringen	Accuraatheid metingen	Afweging impact gebruik
verhoogde health anxiety		Aanpassingen	Afweging impact gebruik	Inzicht lichaam	Toetsen ervaringen	Beleving vs. Meting	Inzicht activiteiten	Accuraatheid metingen
onveranderde health anxiety		Aanpassingen						
toegenomen stress perceptie		Aanpassingen	Toetsen ervaringen	Inzicht lichaam	Inzicht activiteiten	Beleving vs. Meting	Accuraatheid metingen	Afweging impact gebruik
onveranderde stress perceptie		Beleving vs. Meting	Aanpassingen	Inzicht lichaam	Toetsen ervaringen	Inzicht activiteiten		
verlaagde stress perceptie		Inzicht lichaam	Afweging impact gebruik	Toetsen ervaringen	Aanpassingen	Beleving vs. Meting		
Overig	Dit is voor stukjes die niet relevant zijn							
neutraal over feedback		Inzicht activiteiten	Toetsen ervaringen	Inzicht lichaam				
kritiek smartwatch neutraal		Afweging impact gebruik						
bevestiging ervaring		Aanpassingen	Inzicht activiteiten	Inzicht lichaam	Toetsen ervaringen	Beleving vs. Meting	Accuraatheid metingen	Afweging impact gebruik
omgang smartwatch		Inzicht lichaam	Aanpassingen	Beleving vs. Meting	Inzicht activiteiten	Toetsen ervaringen		
verhoogd inzicht lichamelijke signale		Toetsen ervaringen	Inzicht lichaam	Inzicht activiteiten	Beleving vs. Meting	Accuraatheid metingen	Afweging impact gebruik	Aanpassingen
onwetendheid metingen		Inzicht lichaam						
verklaren meting		Accuraatheid metingen	Beleving vs. Meting	Inzicht lichaam	Toetsen ervaringen			
beleving vs meting		Beleving vs. Meting	Aanpassingen	Accuraatheid metingen	Toetsen ervaringen	Inzicht lichaam	Afweging impact gebruik	
belangerijk health anxiety		Aanpassingen	Toetsen ervaringen	Beleving vs. Meting				

Inzicht activiteiten Afweging impact gebruik Inzicht lichaam Accuraatheid metingen

Appendix 8: Expanded theme descriptions

Appendix 8.1: Physiological Insight

The sub-theme of Physiological insight is "Insights into the bodily reactions within daily routines". Participants used the smartwatch to gain insight into their bodies and how they responded in certain situations. They were curious about how their daily routine would be compared to others or what the readings of the smartwatch would be during or after exercise. A specific interest in stress (12/14), sleep (8/14), and heart rate (13/14) was common among the participants. This physiological insight was new for participants, and nine noted how they considered this information could be used to improve their lives.

Some participants expressed that not all insights were clear in what they meant. Readings like HRV, Ox and respiration were rarely understood by participants and caused confusion about what they meant or how it was relevant to them. Other participants were confused by what the numerical representation of stress meant or what it meant to be in higher stress levels (4/14). One participant responded as follows:

"The smartwatch, of course, indicates a stress level as a number, but yeah, what that number exactly means, that's still vague for me. So, if I had a certain stress level, I didn't necessarily know if it was high or low." (Participant #11414)

This newfound insight shows how participants get accustomed to the smartwatch's functionality and how real-time data can give them valuable information about their physiological reactions. However, participants also expressed confusion about what the numbers mean or what they say about them. This shows how using the device can give valuable insights but can also cause confusion about its meaning.

Appendix 8.2: Accuracy of Measurement

The sub-theme Accuracy of Measurements is defined as “The extent to which users trust the accuracy of the smartwatch’s measurements.” This sub-theme examines all opinions from participants regarding their perceived accuracy of the smartwatch's data. Almost all participants had something to say about their perceived accuracy of the measurements (13/14). Most participants had differing opinions about the measurements, trusting some and doubting others. Overall, doubts about the accuracy were expressed most often (n = 30 quotations) and were mentioned in eleven interviews.

Except for one, all doubts regarding measurements were related to stress. Participants doubted the accuracy as they did not align with their experience. This doubt of alignment with their personal experiences caused doubt in the accuracy of the measurements. One participant expressed this as follows:

"Sometimes I found the stress levels quite strange because it didn't feel like I was stressed, but the device indicated that my stress was high." (Participant #11441)

Overall, all participants considered some measurements accurate (n = 27). Specific measures mentioned were heart rate, which was most often expressed as accurate (n = 9), accompanied by stress (n = 5), sleep (n = 2) and respiration (n = 2). None of the participants expressed why specifically they thought heart rate, sleep or respiration were accurate.

Ten out of the fourteen participants mentioned how they thought the measurements were inaccurate in some way (n = 21). Stress was often mentioned when talking about inaccuracies (n = 13). Similar to the doubts about the accuracy, participant thought the measurements were inaccurate because they did not align with their personal experience. As a result, some participants did not see this feedback as relevant. One participant explained his thoughts about the stress feedback:

"I didn't really see it as structural feedback, or anything like that. Or as accurate feedback. For example, my stress levels were just through the roof every day, while it was just because I was exercising every day. So yeah, I thought, well, for me it didn't seem right, so yeah, then you don't do much with feedback." (Participant #11440)

Overall, opinions about the accuracy of the measurements vary between and within participants. The stress measurements are clearly the most discussed, with a stronger doubt than trust in their accuracy. Discrepancies between personal experiences and measurements cause doubt of the perceived inaccuracy, showing how this is an important factor for trusting in feedback.

Appendix 8.3: Considerations Impact of Use

The sub-theme Considerations Impacts of Use is defined as the User's beliefs regarding the impact of smartwatches on individual and societal levels. Many participants (11/14) expressed positive experiences regarding the smartwatch use and design. Six participants had some critiques of the smartwatch; they had experienced skin irritation from

the wristband or had trouble with the controls and screen. All participants (14/14) had some positives about the personal impact of the smartwatch. They felt they gained valuable insights into their activities and health, felt comforted by measurements, and were incentivised to perform more physical activity. Participants were able to review these positive experiences and imagine how they could have a positive impact on a societal level, with one participant saying:

"Yeah, I actually think it's a good tool. Besides myself, there are obviously more people who sometimes need to get off their lazy butt (....) if you do have that confirmation after your activity of 'wow, I did it like this and that', then that challenges you to do better next time. Especially if, for example, you go running, well, then you can eventually see your pace in the app. And when you see that, after two times, my pace has increased, that of course motivates you enormously to go running again next time and do even better." (Participant #11426)

However, some downsides to smartwatch use were also mentioned. Critiques included the high price of the device, how it was distracting, and some privacy concerns were mentioned. However, the most prominent critique was expressed by seven participants who mentioned how people could become obsessed with using the smartwatch. They thought that people could rely too much on their smartwatches and that individuals could become obsessed with their data. One participant explained it as follows:

"And, I think for others, but for other people, it can actually go in the wrong direction. And then I'm thinking of someone who has a strong need for control, you know, that they might get too caught up in it. I personally believe that that's never good." (Participant #11441)

This sub-theme shows the difference between participants' opinions on the use of smartwatches on the personal and societal levels. In general, participants were positive about their personal use of the smartwatch. They experienced various positive effects and reflected how their personal experience could have a similar positive effect on others. However, participants are also aware of the possible negatives of smartwatch use. By far, the largest critique on the use of smartwatches was the possibility of obsession; participants believe others could become obsessed with the feedback and data of the smartwatch.