Exploring the Impact of Wearable Devices on Perceived Stress and Health Anxiety in Daily Life

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Abstract

The growing popularity of wearable devices, particularly smartwatches, for monitoring stress raises questions about their psychological effects. This study aimed to examine whether receiving physiological stress feedback influences individuals perceived stress and health anxiety in everyday life. Specifically, it addressed three research questions: (1) How does wearing a smartwatch affect retrospective perceptions of stress? (2) Does it impact health anxiety levels? (3) How does it influence perceived stress in daily life? The study was a two-week within-subject design with 70 participants. They wore a wearable during one of the two weeks, depending on the group allocation. Participants filled out retrospective questionnaires, the ones relevant for this study are the Perceived Stress Scale (PSS) and Short Health Anxiety Inventory (SHAI). They also completed assessments via an Experience Sampling Method (ESM) app four times a day.

Linear mixed models showed a significant decrease in PSS and SHAI scores from baseline, which was the initial meeting, to the wearable condition, the week the wearable was worn. However, there were no significant differences between the wearable and no wearable week, nor in the ambulatory perceived stress measured by ESM.

The findings suggest that wearable stress feedback does not elevate perceived stress or health anxiety in healthy individuals and may even enhance short-term stress awareness. Future research should examine long-term use and engagement by the participants, to understand the full psychological implications when tracking stress using wearables.

Key words: wearables, health anxiety, perceived stress

Exploring the Impact of Wearable Devices on Perceived Stress and Health Anxiety in Daily Life

The use of wearable devices, especially smartwatches, is growing rapidly, as two in five consumers own such a technology (Pham, 2025). These devices can be used to track health-data, such as stress. However, this widespread use has raised concerns, that focus on the potential to increase health anxiety and change how users perceive stress. Despite the interest in this area, empirical research with data collected in daily life settings remains limited. Stress is a psychological state, but it is also a physiological process that can impact a person's health (Epel et al., 2018). Chronic stress has been linked with a higher risk of several diseases, including cardiovascular disease and hypertension (Epel et al., 2018). Consequently, the attention on stress measurements and management has gained prominence, as these practices allow individuals to measure, become aware of, and regulate their stress response. Smartwatches represent one type of wearable that, among many other features, offers physiological feedback in real-time, including feedback on stress (Jerath et al., 2023). Heart rate variability (HRV) and other physiological indicators are the base for the feedback provided by wearables (Jerath et al., 2023). It allows users to monitor fluctuations throughout the day (Jerath et al., 2023; Booth et al., 2022). There is a possibility that proactive stress management results from the feedback; however, it may also increase health anxiety. That is because it raises awareness of stress scores and bodily signals that individuals may not notice otherwise. The current study aims to investigate people's psychological reactions to wearables in daily life, with a particular focus on how feedback in the form of stress scores impacts perceived stress and health anxiety.

Stress

Stress is a multifaceted construct that encompasses physiological, psychological, and behavioural components. It refers to the response to a perceived threat or challenge, known as a stressor (Brivio, 2022; Valencia-Florez et al., 2023). Stressors may be external, such as job demand or interpersonal conflict, or internal, such as negative thoughts or emotional distress. The response involves both physiological activations, such as changes in heart rate, and psychological appraisals, or the subjective evaluation of the stressor's significance, perceived stress (Valencia-Florez et al., 2023).

According to the World Health Organization (2023), stress is "a state of worry or mental tension caused by a difficult situation". This definition reflects the perceived dimensions of stress that vary between individuals and contexts. The physiological stress response stems from the activation of the ANS, specifically the sympathetic-adrenalmedullary axis and the hypothalamic-pituitary-adrenal axis, which prepare the body for action (Tsigos et al., 2020).

There are different kinds of stress, long-term and short-term stress. Short-term or daily stress lasts for a limited amount of time and has the purpose of survival. It affects how an individual reacts to everyday challenges (Epel et al., 2018). It is adaptive and helps individuals to cope with immediate demands. However, when it is persistent and accumulates, it can lead to long-term or chronic stress. Then stress can become a problem, as there can be multiple negative effects on health (Kraaij et al., 2020; Chalmers et al., 2021). For example, individuals with chronic stress report higher levels of perceived stress, and it has been linked to cardiovascular disease and hypertension (Epel et al., 2018). Furthermore, stress affects not only induvial but also broader systems such as the economy. For instance, work-related stress leads to illnesses, and the costs for the economy are estimated between US $221 million to US $187 billion annually (Kraaij et al., 2020). Thus, stress should not be solely viewed as a negative experience. While chronic stress contributes to health problems, its acute form serves an important adaptive function, enabling individuals to cope with demands. As awareness of stress and the effects of it continue to grow, individuals look for possibilities to understand and manage their response to stress better. One such possibility is the use of wearable devices, as they give real time physiological feedback.

Wearable Devices and Physiological Feedback

To monitor their own health and wellbeing, people are increasingly turning to mobile technologies (González-Ramírez et al., 2023). One such technology is wearables, which can be defined as devices that can be worn on the human body or clothing (Iqbal et al., 2021). Smartwatches, worn on the wrist and a widely used wearable, are equipped with sensors that measure heart rate, track physical activity, and provide other health-related metrics (Jerath et al., 2023). While initially used to track sport and fitness, smartwatches are now frequently used in everyday health monitoring (González-Ramírez et al., 2023).

Wearables can provide stress feedback to the user in the form of a numerical stress score, which is partially based on HRV. Such feedback may increase awareness, which in this context refers to the ability to notice physiological changes and reflect on stress level. However, there are concerns about the quality of the data gathered by wearables, as contextual factors, such as physical activity or psychological stress, can influence HRV and other physiological indicators (Geus & Gevonden, 2024; van Lier et al., 2020). Interpretation of stress data provided by wearables thus requires caution, especially when individuals are not aware of the variables that affect their scores (Geus & Gevonden, 2024).

A wearable typically provides real-time feedback on not just HRV but also heart rate and stress scores ranging from 1 to 100. With Garmin devices, stress scores are mainly based on HRV (Rosenbach et al., 2025). When wearing a wearable, individuals can immediately see their stress scores at any given moment. This feedback may help individuals to recognise personal stress patterns and triggers (Mozgovoy, 2019). Further, it can help in adopting healthier coping strategies, such as relaxation techniques (Jerath et al., 2023; Mozgovoy, 2019). As in the case of HRV, a careful interpretation of the score is also necessary for the displayed heart rate and stress score data (Geus & Gevonden, 2024; van Lier et al., 2020). However, misalignment between the subjective experience of stress and the objectively measured stress can lead to confusion, frustration or disengagement from the wearable (van den Berg et al., 2025). This is notably the case when an individual does not understand the meaning of specific values, such as the stress score. Further, in case an individual has pre-existing chronic stress, establishing a meaningful baseline stress score may be difficult (van den Berg et al., 2025). This underlines why it is important to understand how stress is measured, as the interpretation of the feedback given by the wearable is only meaningful, when it was assessed correctly. How stress can be measured and managed will be explored in the next section.

Stress Measurement and Management

To gain a thorough understanding of the impact of stress, it is important to differentiate between different types of stress responses and their measurement. On the one hand, there is perceived stress, so how individuals interpret their experiences subjectively, and physiological stress is indicated by measurable bodily functions such as heart rate. Self-report measurements, such as the Perceived Stress Scale, are used to measure perceived stress, and they assess the degree to which individuals feel overwhelmed or unable to cope. Physiological stress is measured through biological signals, such as heart rate or HRV, which indicate ANS functioning non-invasively (Jerath et al., 2023).

HRV is widely used to indicate stress, though careful interpretation is necessary. The given value represents fluctuating length of intervals of the heartbeat of individuals (Kim et al., 2018). High HRV generally indicates a more adaptive, flexible nervous system, and thus better stress regulation, while stress and poor health are linked to low HRV (Jerath et al., 2023; Kim et al., 2018). In addition to physiological stress, HRV is influenced by other factors, such as physical activity, sleep and caffeine intake (Geus & Gevonden, 2024). Thus, if individuals are presented with HRV scores by the wearables, these have to be understood in context and handled with caution.

Stress can be measured ambulatory or retrospectively. Ambulatory refers to measuring data in daily life when it naturally occurs, reducing memory bias. Experience sampling methods (ESM) is a method for such data collection. Tools such as wearables and apps can help collect such data. Compared to that, retrospective data requires individuals to recall past experiences and feelings; this can be done through questionnaires. This method relies on memory and thus has the potential for bias or inaccuracies. Conner and Barrett (2012) propose that three conscious selves come into play in self-reporting. First, there is the experiencing self, which reports the feelings that occur at the moment; then there is the remembering self, which reflects on experiences that lie in the past; and there is the believing self, which integrates values and expectations. The experiencing self can be measured through ambulatory self-reports and the remembering self through retrospective questionnaires (Conner & Barrett, 2012). In this study, both the remembering and the experienced self will be examined, with reflections on the past week and several reflections a day, respectively. This approach helps to understand how immediate experiences of stress and their retrospective interpretations may differ.

In everyday life, the complexity of stress becomes clearer. Therefore, studying stress in daily life settings is important when the goal is to understand how stress is experienced outside of controlled environments. Until recently, however, stress was mainly studied in laboratories. Dishman et al. (2000) studied HRV and perceived stress in a controlled environment and found that people reporting higher levels of perceived stress showed lower HRV. However, according to Martinez et al. (2022), in laboratory studies, the stressors are isolated and controlled, while in ambulatory daily life studies, they are not. This stresses the importance of studying stress in daily life. A significant yet small relation between perceived stress and HRV was found in a large-scale in situ longitudinal study (Martinez et al., 2022). Other studies of the effect of a wearable on perceived stress in daily life found no significant effect both ambulatory and retrospectively (de Jong, 2025; Leijser, 2025; Zwakenberg, 2024; van Oostrum, 2024; Zwakenberg, 2024). However, those studies did not have a large sample size, so studying this effect with a larger sample could lead to more representative results.

Vignette studies are often used in research. This is where participants get a scenario and imagine it, and then they answer surveys, a common practice for research about stress (West et al., 2017). In contrast to that, for this study, the participants get wearables to use in their daily lives, and the idea is to look at what it does to them. By doing this, the participants get stress feedback in the moment, and there will be less memory bias when it comes to self-reporting, as they fill in several questionnaires a day. The participants will not be asked about the exact stress score or heart rate provided by the wearable.

By examining both the experiencing and remembering self, this study explores how different self-reporting methods shape the perception of stress. However, beyond self-report, continuous exposure to physiological stress feedback, whether through self-reflection or wearable devices, may also have unintended psychological consequences. For some individuals, positive behaviour change may be the result of using the data, but when they become increasingly preoccupied with their bodily sensations and stress scores, it can lead to increased stress awareness and worry. This raises questions about the relationship between the use of such wearables and health anxiety, which will be explored in the next section.

Health Anxiety

When a person interprets bodily sensations or changes as an indicator of a serious illness, it is referred to as health anxiety (Asmundson et al., 2010). It is an anxiety disorder that is similar to hypochondriasis and illness anxiety disorder (Tyrer & Tyrer, 2018). Health anxiety has an impact on wellbeing. Preoccupation and worry can make the symptoms of health anxiety worse and motivate dysfunctional coping mechanisms (Asmundson et al., 2010). It can lead to frequent doctors' visits to investigate or receive reassurance, which puts a burden on health services that are not necessary (Tyrer & Tyrer, 2018).

A theoretical framework to examine how individuals misinterpret bodily sensations and information related to health is the cognitive theory of health anxiety. This theory states that anxiety comes from negative interpretations, and the symptoms increase negatively with time (Salkovskis et al., 2003). Selective attention bias is one of the cognitive processes that lead to health anxiety. Reassurance from a health professional can lead to both a decrease in the short term and an increase in the long term if it is not handled correctly (Salkovskis et al., 2003). When taking that into consideration, the constant availability of data by the wearables could decrease or increase health anxiety.

Increasing a person's attention to physiological signals and allowing them to self-monitor constantly wearables may contribute to health anxiety. Awareness and behaviour change are possible consequences of wearable feedback, but on the other hand, it may also lead to heightened alertness or excessive worry. This is consistent with findings from digital health research that found frequent online health information seeking to be associated with increased health anxiety (Peng, 2022; Fergus & Dolan, 2014). Additionally, individuals seeking information may be overwhelmed by the information they are presented with. Thus, constant health information can increase health anxiety, which raises the question of whether that is the same for wearables, offering insights into health data.

There are some studies on the topic of health anxiety and wearables. Rosman et al. (2020) found that wearables increased health anxiety in patients with atrial fibrillation due to the constant visibility of data. However, research that involves healthy adults as participants is limited (Conboy et al., 2018). Conboy et al. (2018) found that the use of mobile health apps did not significantly affect health anxiety. Similarily, more recent research by van Oostrum (2024) did not find significant changes in health anxiety, following a two-week study with 22 participants using quantitative methods, which will also be used in this study. Overall, more research needs to be done in order to learn about the effects of wearables on health anxiety, especially in healthy adults and in real-world, everyday settings. These findings point to critical gaps that can be found in literature and will be addressed in the next section.

Knowledge Gaps and Current Study

Despite the growing interest, knowledge gaps remain regarding the effect of wearables on perceived stress and health anxiety. Most studies about stress thus far have been done in a laboratory. There is limited research where stress has been studied in the daily life setting, and there is also not much research that has been done on the impact of wearables on health anxiety. Next to that, often there is no distinction made between different types of self-report, the remembering self and the experiencing self. Compared to traditional retrospective self-reports, there is more research to be done when it comes to ambulatory self-reports using the experiencing self, providing insight into the daily life context. Studies that were similar to this current study saw no significant effects of the presence of wearables on perceived stress or health anxiety (de Jong, 2025; Leijser, 2025; Zwakenberg, 2024; van Oostrum, 2024). However, they worked with smaller samples.

In the current study, due to their availability, wearable devices will be used by participants so they can view their heart rate and stress scores, but no specific values will be reported. Both retrospective and ambulatory questionnaires will be given to the participants, and the impact of wearables on perceived stress and health anxiety in the daily life setting will be investigated. Studying this in daily life instead of in a controlled environment allows researchers to see how it affects individuals in their typical environment. Based on what is discussed before, there are the following research questions and hypotheses:

RQ1: How does the presence of the wearables influence individuals' retrospective perception of stress?

H1: Wearing the wearable will not significantly affect retrospective perceived stress compared to baseline.

H2: Wearing the wearable will not significantly affect retrospective perceived stress compared to not wearing the wearable.

RQ2: How does the presence of the wearables influence individuals' retrospective perception of health anxiety?

H3: Wearing the wearable will not significantly affect retrospective health anxiety compared to baseline.

H4: Wearing the wearable will not significantly affect retrospective health anxiety compared to not wearing the wearable.

RQ3: How does the presence of the wearables influence individuals' ambulatory perception of stress in daily life?

H5: There will be no significant difference in ambulatory stress levels between the wearing a wearable and not wearing a wearable.

Methods

Research Design

This two-week-long study used a quantitative, within-subject design. Data was collected through daily self-report questionnaires and three longer retrospective assessment questionnaires, enabling the measurement of the dependent variables both ambulatory and retrospectively. Although multiple psychometric instruments were administered as part of the study, the present analysis focuses on two specific measurements relevant for the research questions.

Participants

The researchers of this study recruited 96 participants. A convenience sampling method was used, thus researchers asked people from their close social environment. Further some participants were recruited using SONA, a system from the University of Twente where psychology students can sign up for studies of fellow students. An inclusion criterion was that participants had no previous experiences with smartwatches measuring HRV. After omitting some participants due to missing data or being under the age of 18 there were a total of 70 participants, 27 of which identified as men and 43 as women. The ages of the participants ranged from 18 to 59 (M=27.19, SD=11.38). When it comes to highest level of completed education this far two participants are still in school, and 22 participants have completed High School. Furthermore, 13 participants completed Intermediate Vocational Education, 10

Higher Vocational Education and 23 Scientific Education. Different nationalities were represented in this sample with 56 being from the Netherlands, 5 from Grece, 4 from Germany, and 5 from other countries. Recruiting participants happened over a period of three months. The BMS Ethics Committee at the University of Twente and the Ethics Review Board of the University of Tilburg granted ethics approval for this study.

Materials

There are several materials needed for this study. These included an information sheet for participants about the study and stress specifically, wearable devices that can deliver stress feedback, two types of software to deliver questionnaires to participants, namely Qualtrics and m-Path as well as the different questionnaires used.

Psychoeducation

To explain to the participant what the study is about and what everything they need to know regarding the wearables, a psychoeducation sheet was created. The entire sheet can be found in Appendix B. It included a summary of the study, instructions for the week where the wearable is worn, information about stress, stress feedback and lastly stress management. This was shared with participants in the meeting in which they received the wearable, to enable them to get an understanding of what the stress score for example means and how to interpret it, but also to be aware that there can be measurement errors.

Wearables

For this study there were two types of wearables used. One of them was the Garmin Forerunner 255 (https://www.garmin.com/en-GB/p/780139). It can monitor a person's health and show how they perform physically. The watch has many features but for this study the important factors were heart rate and stress score, which is why they were displayed on the main display next to the HRV and time as can be seen in Figure 1. All watches that were given to the participants were set up identically, showing the same display and participants were asked not to change it. Next to the watch itself, a charger was also given to the participants, in case the battery got low. When the participants received the watch, they also got additional information, such as that the watch is water resistant and should be worn at most times but could be taken off during sleep, while showering or doing sports.

The other watch used in this study is the Vívosmart 5 (https://www.garmin.com/en-GB/p/605739/) by Garmin. This watch is similar to the last one. However, the stress score could not be added to the main display which is why it was necessary to add it as an extra widget, just like the heart rate. To get to these other screens it is necessary to swipe up or down. The aim was to keep the display design as simple as possible here as well, so other things were added. The participants were also asked not to change anything. The main display, as can be seen in Figure 2, had a little downside as the steps and heart rate were meant to be visible, however with a tap on it, it would switch to other values. Then it was necessary to tap a couple more times to get back to the original one.

Figure 1

A photo of the Garmin Forerunner 255 watch. It shows the display with the time, heart rate, HRV and stress score.

Figure 2

A photo of the Garmin Vivosmart 5 watch including the main display showing the time, number of steps and heart rate. The other screens show stress score and heart rate.

Qualtrics

The online platform Qualtrics (https://www.qualtrics.com/) was used for the retrospective self-reports. It is possible to create questionnaires with Qualtrics and then distribute it to participants via a link that was sent to them. They could then use their phones or laptop to fill the questionnaires in. There was one questionnaire at each meeting with the participant and the questionnaires can be found in Appendix C.

m-Path

m-path (https://m-path.io/landing/) is an online platform that was used to let the participants fill in daily questionnaires. The participants had to download the m-path app where they received notifications several times a day to fill in questionnaires. On the days of the meetings the participants did not receive questionnaires. The questions of the four questionnaires can be found in Appendix D.

Questionnaires

Perceived Stress Scale. To measure perceived stress the Perceived Stress Scale (PSS-10) was used. There are ten questions in this questionnaire, and it can be answered with a five-point Likert scale ranging from 0 (“never) to 4 (“very often”). According to Lee (2012), the scale has good internal consistency and Cronbach's alpha is .83. The PSS-10 was part of all three Qualtrics, so retrospective, questionnaires. In this sample, the Cronbach's alpha of the PSS-10 was .85 at the baseline meeting, .88 at the follow up after the wearable was worn and .86 at the follow up after the wearable was not worn.

Short Health Anxiety Inventory. To measure Health anxiety the Short Health Anxiety Inventory (SHAI-14) was used. It consists of 14 statements and the participant must pick between 0 ("never), 1 ("occasionally"), 2 ("much of the time") and 3 ("most of the time"). According to te Poel et al. (2017) the SHAI-14 has good internal consistency and Cronbach's alpha is .92. This questionnaire was also part of all three Qualtrics questionnaires. The Cronbach's alpha of the SHAI of the baseline questionnaire of this sample was .86, while it was .81 at the follow up after wearing a wearable and .86 at the follow up after not wearing a wearable.

Stress in Action. This study was done in collaboration with the University of Tilburg, in an effort to create a large pool of data. With the duration for each participant taking 2 weeks, it is a lengthy study and with more researcher a larger data set can be created more easily. Moreover, this study was conducted under the framework of Stress in Action, which aims to research stress in daily settings. To be able to answer the second research question the item "I feel stressed today" of the m-Path questionnaires was used (Vaessen et al., 2023). It is one of the items of the ESM Item Respiratory (https://esmitemrepositoryinfo.com/). This item was picked, as it is a question that was asked to the participants at all four points during the day, making it more reliable.

Other Questionnaires not Relevant for this Study. As this study is part of a bigger project, there are many questionnaires given to participants that are not relevant for the present thesis and its research questions. The other questionnaires include the relaxation state questionnaire, stress mindset, emotion regulation questionnaire, multidimensional assessment of interoceptive awareness and the big five inventory.

Procedure

Once a participant was directly recruited by a researcher or enrolled via the SONA system, basic information about the study was sent and an intake meeting was scheduled. A quiet room were the participants, and researcher would not be disturbed was chosen as the location for the meetings and booked if necessary. The researcher put the participant in one of the two groups, either getting the watch in the first or in the second week, making sure it is an even split between all participants. During this meeting the information about the study, its purpose, the structure and what participants could expect was shared and informed consent

(Appendix E) was signed. After that the participant code was created and the first Qualtrics questionnaire, the baseline questionnaire, was filled in by the participants. Following that the m-path app was installed and the researcher made sure the participants added the right study, ensuring they would get the notifications starting the following day. If participants were to receive the watch in the first week the psychoeducation information sheet was explained, so that the participants were able to understand what the different scores mean. Next to that, more important information was given, such as checking the watch and the scores it is giving regularly. Lastly, the participant and researcher agreed on meeting in one week's time.

During the week four questionnaires were scheduled to be sent via m-Path. The morning questionnaire notification would come at 07:00 and a reminder at 07:45. But the questionnaire is available until 10:30. During the day there were two questionnaires, but the times were random and different every day. One was roughly sent between 12:00 and 14:00 and the other somewhere between 16:00 and 18:00. After the original notification the participants would also get a reminder 45 minutes later. These questionnaires could be answered for a total of 90 minutes. For the last questionnaire of the day, the evening questionnaire, participants got a notification at 20:00 and a reminder at 20:45. The questionnaire could be answered until roughly 23:30. Some participants had problems with the notifications.

During the second meeting participants that wore the watch over the last week returned the watch including the charger. Next to that the second Qualtrics questionnaire was made available to them, and they filled it in. There were different links, depending on whether participants wore the watch or not. The participants that were supposed to get the watch in the second week the psychoeducation information was given now. They were further instructed on how to handle the watch and what is expected of them, just like the other participants a week prior. Lastly, a third meeting was scheduled in one week later.

During this week all of the participants were expected to fill in the m-Path questionnaires again. As this is much to ask of participants, the researchers kept an eye on the response rates and checked in with the participants if necessary. The response rate should not be below 70%.

The last meeting allowed the participants that had the watch the previous week to give it back. If the participants had any remarks about the watch the researchers would note it down. Next to that, the last Qualtrics questionnaire was sent and filled in by participants. Lastly, the researchers thanked the participants for their participation.

Data Analysis

All statistical analyses were conducted using R-Studio (version 2024.12.0+467) with R (version 4.5.0). The data was exported from m-Path and Qualtrics and subsequently imported into R-Studio for preprocessing and analysis.

First, participants under the age of 18 were excluded from the Qualtrics dataset. Then a dataset was created that did not include the questionnaires not relevant for this study. As the Qualtrics data set did not include an order variable, so whether the watch was worn in the first or in the second week, this information was taken from the m-path data and added to the Qualtrics dataset. This was then made into a dummy variable in a new column, 0 for wearing the watch in the first week and 1 for wearing it in the second week, to facilitate analysis.

Next, Participants with incomplete data were excluded from Qualtrics dataset, resulting in a final sample of 70 participants. For the PSS scale, items 4, 5, 7 and 8 we reverse-scored for all three timepoints: baseline, wearable and no wearable. The total scores for PSS and SHAI were computed at baseline and bot of the conditions. Following that descriptive statistics were computed.

The data were then reshaped into long forma, with participant alias included as a random intercept, as well as the dummy variable and the total scores. The same process was applied for the SPSS and SHAI data, leading to two new data sets. To examine the relationship between the total scores of the PSS and SHAI, Pearson's correlation coefficients were calculated.

Data visualisations were generated to explore trends across condition. To compute a linear mixed model (LMM) for both the PSS and the SHAI, the model was first fitted. Then key parametric assumptions, namely normality, homoscedasticity and linearity, were tested. After they were all met, the LMM were analysed using Wear as the reference category. Based on that research questions one and two could be answered. The dependent variable were the PSS score and the SHAI score respectively and the independent variable was wearing the wearable or not.

Other steps were taken for the m-path data. The dataset was reduced to the Order wearable, the occasion (including week, day and time of day), the alias, and the score for stressed_sliderNeutralPos, which stems from the ESM item "I feel stressed today". Weekly averages of the state scores from daily life were created to compare one week with the other. After calculating descriptive statistics, the data was visualised. Then a LMM was fitted with the momentary perceived stress as the dependent variable, wearing a wearable or not as the independent variable and participant alias as a random intercept. With that research question three could be answered.

Results

This section presents the results from the Qualtrics baseline, wearable and no wearable questionnaires, as well as the Experience Sampling Method (ESM) data collected in the m-path app.

Qualtrics

Descriptive Statistics

First, descriptive statistics were calculated, which allowed an overview of the retrospective data set. Means, standard deviations and total score ranges of PSS and SHAI can be found in Table 1. To put it into context 0 to 40 is the theoretical range from PSS scores and of SHAI it is 0 to 42. As mentioned before, baseline is the first moment that was measured right at the start of the study and Wear and NoWear are the two conditions where the wearable was worn or not. The correlation between the PSS and SHAI scores can be found in Table 2. All three conditions show a significant correlation, with the correlation in the baseline questionnaire being the strongest, suggesting a moderate positive association between perceived stress and health anxiety

Table 1

Descriptive Statistics for PSS and SHAI

	PSS (M, SD)	PSS Min-Max	SHAI (M, SD)	SHAI Min-Max
Baseline	25.4 (5.48)	16-38	24.4 (5.71)	17-44
Condition				
Wear	23.3 (5.72)	13-40	23.4 (4.98)	15-39
NoWear	22.7 (5.25)	11-35	23.4 (5.65)	14-45

Note. PSS = Perceived Stress Scale; SHAI = Short Health Anxiety Inventory. Each condition includes data from 70 participants.

Table 2

Pearson's Correlations Between PSS and SHAI Scores

	r	*t*	df	*p*	95% CI for r
Baseline	0.51	4.82	68	<.001	[0.31, 0.66]
Condition					
Wear	0.26	2.24	68	.029	[0.03, 0.47]
NoWear	0.33	2.93	68	.005	[0.11, 0.53]

Note. For each condition there is correlation coefficients (r), t-values, degrees of freedom (df), p-values, and 95% confidence intervals (CI) shown.

Potential Order Effects

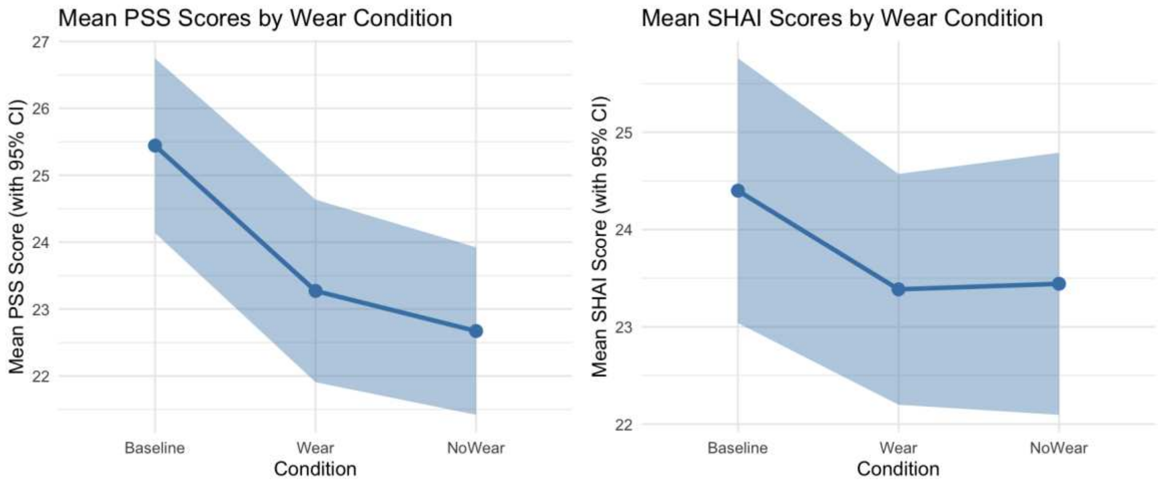
To examine whether the time when participants wore the wearable (week one or week two), influences outcomes, a wearable order was added to the data set as a moderator. It was explored using descriptive statistics and visualisations (Appendix F). Linear models for PSS, SHAI and ESM, were also created; however, baseline was used as a reference category, which is different from the primary analyses that will follow. Across the three models there was no significant effect or interaction found which included order. The full models can be found in Appendix F.

Preliminary Visualisation

Next these descriptive statistics were visualised to explore the initial trends in stress and health anxiety more. Figure 3 displays the mean trajectory of PSS and SHAI scores across the three conditions (Baseline, Wear, No Wear). The solid lines represent the average scores, and the shaded areas indicate the 95% confidence intervals around the means. Both perceived stress and health anxiety decreased from baseline to Wear. There is little difference observed between Wear and NoWear. The confidence intervals between Wear and NoWear overlap heavily and thus imply little to no reliable difference between both conditions. In Appendix G additional visualisation can be found that offer a more in-depth analysis yet were not necessary to answer the research questions.

Figure 3

Mean trajectories of PSS-10 and SHAI-14 scores by Wear Condition



Note. The lines represent the mean scores for the PSS and SHAI across the three conditions, Baseline, Wear and No Wear. The shaded areas indicate the 95% confidence intervals.

Linear Mixed Models

Perceived Stress. To address research question 1 and thus determine the effect of the presence of a wearable on retrospective perceived stress a LMM was fitted with a random intercept for participant alias. Using Wear as the reference category, stress was significantly higher reported at baseline compared to the Wear condition. The NoWear condition on the other hand did not significantly differ from the Wear condition. These results indicate that perceived stress was highest at baseline, so before wearables were involved, and reduced significantly after that, but without a significant change from Wear to NoWear condition. The order in which the wearable was worn was not explicitly modelled in this analysis. Table 3 shows full estimates of this LLM. The parametric assumptions, namely normality, linearity and homoscedasticity were tested. All figures regarding parametric assumptions can be found in Appendix H. The assumptions are all met and thus support the validity of this model.

Table 3

Fixed Effect Estimates from Linear Mixed Model Predicting PSS Scores (N=210 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept (Wear)	23.27	0.66	105.23	35.48	<.001
Baseline	2.17	0.51	138.00	4.24	<.001
NoWear	-0.60	0.51	138.00	-1.17	.245

Note. Reference category for condition is Wear. All p-values are two-tailed. The model includes a random intercept for alias (participants).

Health Anxiety. To address research question 2, a LMM was fitted to determine the effect of the presence of a wearable on health anxiety with a random intercept for participant alias to account for repeated measures. The Wear condition was used as the reference category. There is a significant effect of the baseline condition compared to the Wear condition. This indicates that participants reported significantly higher SHAI scores at baseline than when wearing the wearable. Further, there was no significant difference between the NoWear and the Wear conditions. These results indicate that perceived stress was highest prior to using a wearable, at the beginning of the study, and decreased after that. But between Wear and NoWear it remained stable, without any significant changes. Fixed effect estimates can be found in Table 4. Parametric assumptions of this model were assed and met, underlining its validity and can be found in Appendix H.

Table 4

Fixed Effect Estimates from Linear Mixed Model Predicting SHAI Scores (N=210 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept (Wear)	23.39	0.65	92.60	35.87	<.001
Baseline	1.01	0.43	138.00	2.38	.019
NoWear	0.06	0.43	138.00	0.13	.894

Note. Reference category for condition is Wear. All p-values are two-tailed. The model includes a random intercept for alias (participants).

Experience Sampling Method Data

The ESM data collected via m-path provided insight into within-day fluctuations. Of the 93 initial participants people with a compliance rate that was lower than 70% were omitted, which led to a data set of 70 participants. Table 5 shows the descriptive statistics by group.

Table 5

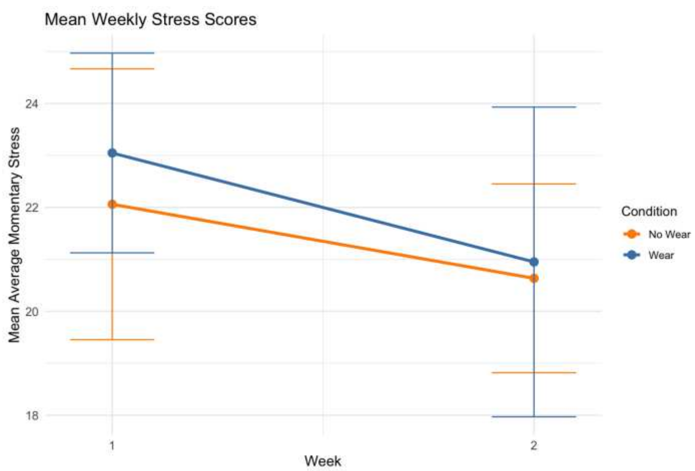
Descriptive Statistics

Group	Min	Max	Mean	SD	Variance	N
Control	0	100	21.1	19.7	387.	1420
Smartwatch	0	100	21.9	20.7	429.	1476

Next, the data in form of weekly momentary stress trends, were visualised using a line plot, that can be seen in Figure 4. The line plot displays weekly average momentary stress scores that are separated by condition, so wear and no wear. Both conditions showed a slight decrease from week 1 to week 2. Both lines run in parallel and thus suggest no clear interaction effect between time and wearable use. Overall, the visualisation suggests only subtle differences in stress levels across condition and time. Further visualisation in form of a boxplot can be found in Appendix G.

Figure 4

Line plot showing the Weekly Average Momentary Stress Scores by Wear Condition



Linear Mixed Model

To address research question 3 and thus investigate whether wearing a wearable influenced average momentary stress, a LMM was fitted. To account for repeated measures the model included a random intercept for participant alias. The analysis revealed no significant main effect of wearable use on momentary stress levels. The coefficient was positive, which suggest slightly higher stress levels when wearing the wearable, however, it was not statistically significant as the difference was small. Table 6 shows full estimates. The model met the parametric assumptions, supporting the validity of the model. They can be found in Appendix H.

Table 6

Fixed Effect Estimates from the Linear Mixed Model Predicting Average Momentary Stress (N=140 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept	21.29	1.62	84.12	13.11	<.001
Wearable(1=yes,0=no)	0.80	1.03	69.00	0.78	.437

Note. Reference category is NoWear. The model includes a random intercept for alias (participant).

Compare ESM with PSS data

Lastly, the relationship between average momentary stress and perceived stress was investigated. To examine this, a Pearsons correlation was conducted, and the results showed a moderate positive correlation, $r(120)=.49$, $p<.001$, 95%CI [.35,.62], indicating that participants who reported higher momentary stress levels also tended to report higher retrospective perceived stress.

A LLM was fitted to investigate whether wearable use and measurement method, PSS or ESM, influence the reported stress levels. A random intercept for participant alias was included. The reference categories were PSS and Wear. The analysis showed no significant main effect of wearable use on reported stress levels. Next, the reported stress derived from ESM did not differ significantly from the one captured retrospectively in PSS. The interaction between the use of wearables and measurement method was also not significant. This suggests that the relationship between wearable use and stress did not differ between methods. All in all, these findings indicate that neither the method nor the presence of a wearable significantly impacted stress levels. Parametric assumptions were met supporting the validity of the model (Appendix H).

Table 7

Fixed Effect Estimates from Linear Mixed Model Predicting Stress Scores by Wearable Condition and Method

(N=262 observations, 70 participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept (PSS, Wear)	23.49	1.35	159.39	17.46	<.001
NoWear (0)	-0.77	1.34	187.51	-0.58	.566
Method (ESM vs. PSS)	-1.40	1.31	190.95	-1.07	.287
Wearable x Method Interaction	-0.03	1.83	187.51	-0.02	.986

Note. The reference category for wearable condition is Wear and for method it is PSS. All *p*-values are two-tailed.

Discussion

This study aimed to investigate people's psychological reactions to wearables in daily life, with a particular focus on how feedback in the form of stress scores impacts perceived stress and health anxiety. PSS and SHAI via Qualtrics assessed retrospective perceived stress and health anxiety and ESM ambulatory perceived stress. The study explored the effect of wearables that display stress feedback on psychological outcomes in daily life. Specifically, the effect of the wearable on retrospective perceived stress (research question 1), retrospective health anxiety (research question 2) and ambulatory perceived stress (research question 3) was investigated. Based on findings of previous research, it was hypothesised that the wearable would not have a significant effect on perceived stress or health anxiety.

Summary of Key Findings

The retrospective data collected via Qualtrics showed similar results for the PSS and SHAI. The first hypothesis is not supported, as there was a significant decrease in perceived stress from the baseline to the wearable condition. However, there was no significant difference between Wear and NoWear, meaning that the second hypothesis is supported. Similarly, health anxiety was also reported significantly lower in the wearable compared to the baseline condition and therefore, is the third hypothesis not supported. No significant difference was found between Wear and NoWear; thus, hypothesis four is supported. Furthermore, perceived stress and health anxiety were moderately correlated, especially at baseline, thus indicating a partial overlap. Regarding ambulatory stress that was collected using m-Path, there was no significant difference between the week with the wearable and without the wearable; thus, the fifth hypothesis is supported. Retrospective and ambulatory stress were moderately positively correlated, which indicates that ambulatory and retrospective stress perception partially overlap. The methods of measurement, PSS and ESM did not significantly affect perceived stress, and there was also no interaction with the use of wearables. To conclude, wearables did not increase or decrease perceived stress or health anxiety retrospectively. Also, feedback from a wearable in real-time had no impact on ambulatory stress in a daily life setting.

Comparison with previous literature

When examining the psychological consequences of using wearables that provide stress feedback, the findings of this study support and build on previous research.

Regarding retrospective perceived stress (first research question), the lack of a significant difference between the wearable and no wearable condition aligns with previous research by van Oostrum (2024), de Jong (2025), Leijser (2025) and Zwakenberg (2024). This previous research relied on small sample sizes. This study includes a larger sample size and thus extends this previous work. A similarity is the duration, as that was two weeks with three meetings as well. These are also daily life studies and found that wearing a wearable did not increase perceived stress as well. These studies did not compare the baseline to the wearable condition. From the baseline to the wearable condition there was a significant decrease of perceived stress, which may be due to more awareness. This aligns with Jerath et al. (2023), who found that the physiological feedback from wearables may raise awareness without increasing negative feelings. Contrary to that, Dishman et al. (2000) found that higher perceived stress was associated with lower HRV. However, this study was done in a controlled setting and did not include healthy adults, like this study does. Therefore, the present study tries to fill the gap and includes a non-clinical sample in a real-life setting. Further, the participants HRV scores were not reported in this study, participants only looked at them. The results together suggest that a wearable and the feedback it provides do not essentially increase perceived stress.

For retrospective health anxiety (second research question), the lack of a significant difference between the wearable and no wearable condition are in line with previous research by Conboy et al. (2018) and van Oostrum (2024). Both studies had healthy adults as participants and found no significant effect of mobile health technologies or wearables on health anxiety. The decrease of health anxiety from the baseline to the wearable condition indicates that there are short-term physiological benefits, due to increased control or understanding. Opposite to that, Rosman et al. (2020) found that health anxiety increased when wearables were used. However, that study was done with a clinical population and thus this present study is an extension has healthy adults were participants and not a clinical population. These results suggest that health anxiety in healthy adults is not increased by a wearable and its stress feedback and there may be psychological benefits.

For ambulatory perceived stress (third research question), the lack of a significant difference between wearable and no wearable condition are in line with the findings of de Jong (2025) and Leijser (2025) in the daily life research they have done. Martinez et al. (2022) found a link between perceived stress and physiology (HRV) in ambulatory real-life settings, yet it was weak. This supports the idea that for healthy people wearables may not greatly change their daily stress experience. Moreover, the distinction of experiencing self and remembering self by Conner & Barrett (2012) is supported by the moderate correlation between retrospective and ambulatory stress scores. This partial overlap shows the importance of measuring both the remembering and the ambulatory self when inspecting perceived stress in daily life.

All of the findings together, suggest that wearables and the feedback they provide is unlikely to lead to psychological distress.

Interpretation of Results

The present study showed a significant decrease from the baseline to the wearable condition for both retrospective perceived stress and health anxiety. However, between the wearable and non-wearable week there was no significant difference found and also not for ambulatory stress levels. Psychological and contextual factors may help explain these findings. Notably, a moderate correlation was found between perceived stress (PSS) and health anxiety (SHAI), especially at baseline. This aligns with the cognitive theory of health anxiety, that suggest that individuals that perceive their environment as stressful, are more concerned about bodily sensations (Salkovskis et al, 2003). As the correlation was strongest at baseline and then declined, there could be a shift of the focus from internal states to the feedback given by the wearables.

Why did perceived stress and health anxiety decrease from baseline to the wearable condition? It could be because the participants got more engaged in the study and benefited from the psychoeducation that was provided to them. Before the information or the real-time feedback, their stress and health anxiety may have been unorganised. The wearable condition added such structure. This supports the idea that if there is more awareness, worry decreases instead of increases (Jerath et al., 2023). Moreover, the visible feedback may have motivated the participants to change their behaviour, as monitoring can lead to a shift in perception.

Why is momentary stress unaffected by the use of a wearable? One factor that may contribute is low engagement with the wearable. ESM checks fluctuations multiple times throughout the day and participants would need to check and interpret their scores consistently for it to shape their momentary experience. Next, a floor effect may have been created by the overall low levels of ambulatory stress observed in the sample. This implies that participants did not experience enough acute stress to influence their real-time stress levels. Moreover, being exposed to each condition for one week may not be enough time for the feedback of the wearable to become part of automatic emotional processing, as that requires repetition and significance. The impact of the feedback may be lower, if what they feel and the score they see are not matching. A slight increase in momentary perceived stress during the wearable week may indicate a temporary increase in stress awareness. However, as this effect is small and not significant it should be cautiously interpreted. These patterns may further be understood through two theories. According to the cognitive appraisal theory the emotional response of individuals depends on how a stimulus and its relevance and meaning are evaluated by an individual (Lazarus & Folkman, 1984). For this study, if a participant did not consider the data of the wearable as meaningful, it may not have influenced the stress appraisals of individuals. The self-regulation theory highlights that motivation and the ability to adjust responses are important when it comes to changing behaviour, not solely receiving feedback (Carver & Scheier, 1981). Participants of this study did not define personal self-regulation goals, and this may have limited the engagement with the data due to the lack of personal relevance for action.

Why did health anxiety not increase? Usually, especially in clinical and anxious population, health anxiety arises when bodily signals are misread as threats (Salkovskis et al., 2003). The participants of this study, however, were healthy adults and thus may be less likely to exaggerate physiological signals. Compared to Rosman et al. (2020) who studied individuals with atrial fibrillation, this group of participants may have viewed the data more neutrally or positively, as they are healthy and free from diagnostic framing.

Further, due to the within-subject's comparisons, short duration per condition and contact with the researcher from the start, participants may have guessed the aim of the study and moderated their responses to it. But as there is no strong effect between wearable and no wearable conditions, this bias is unlikely.

Overall, it can be said, that there are benefits in the short-term like awareness and insight, but to achieve psychological changes that stay, longer use, deeper engagement and clearer feedback is necessary.

Strengths, Limitations and Recommendations for Future Research

This study has several strengths that may offer valuable insight for the effect of wearables on perceived stress and health anxiety. First, the study was conducted in a naturalistic environment, the participants use the wearables in their daily life, so the real-world, which adds to the knowledge there is of vignette studies. Also, to include momentary and retrospective data collection, offered a more complete and nuanced view of perceived stress. The repeated-measures design allowed for within-subject comparisons in different conditions over the two weeks. This made it easier to detect psychological changes. Another strength, that sets this study apart from other studies is the large data set. Through the collaborative data collection more people were reached, and this allows to draw meaningful conclusion from the analysis that come from a larger population

However, there were limitations that must be acknowledged. The two-week study duration may have been insufficient to capture long-term psychological effects. Moreover, two types of wearables were used, and it was not tracked which participant received which model. Connected to that, engagement with the feedback was not measured, as participants did not need to report their stress scores for example, thus it is unclear, how engaged they were. Additionally, the study did not measure psychological constructs, such as interoception, cognitive appraisal or attention bias. However, those are important when the aim is to understand how individuals interpret physiological feedback (Salkovskis et al. 2003). As these constructs are not measured, the psychological mechanisms that underlie the response of participants to the feedback of the wearables cannot be determined with confidence. Furthermore, self-report bias and missing data could have impacted the findings, particularly in the ESM analyses. Lastly, not much research has been done in this field and the hypotheses of this study are mostly based on prior research by other bachelor students, that was therefore not peer-reviewed and is not published in a scientific article (de Jong, 2025; Leijser, 2025; Zwakenberg, 2024; van Oostrum, 2024) and should be interpreted cautiously.

Based on that there are some recommendations for future research. First, extending the study to a longer period might give offer more details if the effects stay the same over time and allow participants to develop a habit of checking the wearable feedback. Further, it would be best if all participants would use the same wearable. If that is not possible, keeping track who wore what wearable may deliver necessary insights. It would also be valuable if future studies include measures of interoception, cognitive appraisal or attentional focus, as that would clarify how the feedback is interpreted by the participants and how they emotionally respond to it. Incorporating goal setting or reflection as self-regulation strategies would help in understanding how effective the feedback is. To ensure participants engage with the wearable it may be better to report their current stress scores in the ESM questionnaires, as this also allows to compare objective and subjective data. Finally, due to the number of participants this study only focused on the group level, however, individual patterns might also be insightful regarding who is most responsive to such an intervention.

Practical Implications

The findings of the study allow for cautious optimism when it comes to using wearables to self-monitor stress. With healthy participants neither perceived stress nor health anxiety increased. Therefore, to use such devices to self-track may be acceptable and not be a psychological risk. However, as there were no strong effects, passive feedback without engagement may not be able to lead to change that is meaningful. As an implication for the design of future interventions, guidance in psychoeducation may be more beneficial and lead to more engagement if it is done in more depth, interactive and goal oriented. In line with self-regulation theory, setting personal self-regulation goals or reflecting on the meaning of the feedback given may be advantageous. The current study did not include such components of behaviour change but including them may lead to a change from awareness of the feedback into action.

Conclusion

This study investigated the impact of using wearables, which provide stress feedback, on perceived stress and health anxiety in daily life. After the introduction of a wearable perceived stress and health anxiety both decreased, however there was no significant effect between wearable and no wearable condition. Based on these findings it can be assumed, that in a population of health adults, the feedback provided by wearables together with psychoeducation, which explains individuals how to interpret it, may increase awareness in the short-term, instead of worry. The data of ambulatory perceived stress also suggests no significant difference between wearing a wearable and not wearing it. This supports the idea that feedback received passively is not enough and individuals need to actively engage with it.

Overall, psychological harm does not appear to be caused by the use of wearables when it comes to healthy adults. Short-term stress awareness may be a consequence. Future studies could do such a study for a longer duration and include self-regulation strategies and encourage engagement.

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Appendix A

AI statement

During the preparation of this work the author used ChatGPT (Open AI) in order to assist in programming and debugging of code in R, not using the actual data, and to help with the flow of text and structure. It was also used for brainstorming. Further Grammarly was used to help with grammar and spelling. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the final content of the work.

There were different prompts used. One such prompt was: “I am a university student writing my bachelor thesis, what part of my paper should be improved in terms of structure, grammar and clarity. Give specific feedback and be critical in doing so. I am following APA guidelines.”

Appendix B

Psychoeducation

Information Sheet Psychoeducation Group English Version

Study on Stress Wearables

Summary	We are using wearables smartwatches that are worn on the wrist, to gain insight into the influence that stress feedback has on perceived stress, health anxiety and challenge threat appraisals.
Instructions	We would like you to wear the wearable for one full week. You can choose which wrist you would like to wear it on, and you should feel slight pressure when you wear it. Please check your stress level multiple times throughout the day. The smartwatch has many other features, which we would like you to not pay attention to nor use. The watch may run out of battery at some point, so you are also provided with a charger. We would like you to wear the watch all day, however you are allowed to exercise, to sleep and shower without it, besides the fact that it is waterproof.
Stress	Stress can be good, describing manageable levels that promote growth, and bad, describing chronic stress that can cause diseases and mental issues. Stress can be measured in different ways, but for the sake of this study we will focus on physiological stress, which describes the body's reactions to stress demonstrated in high heart rate.
Stress feedback	The wearable indicates stress via four different levels: -Resting State: 0-25 -Low Stress: 26-50 -Medium Stress: 51-75 -High Stress: 76-100 Please be aware that those stress levels can indicate either good or bad stress and the wearable cannot measure that. If the wearable indicates for instance high stress it would be a good time to check with yourself how you feel about this and if you are ready for more challenges or a small break.
Stress management through wearables	Wearables measure physiological signals through an optical sensor, at the back of the watch. However, measurements are often inaccurate. Keep in mind that stress measurement through wearables is not perfect BUT it can also be a helpful tool to self-check and manage your stress.
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Appendix C
Qualtrics Questionnaires

MML-StressWearables - Baseline

Start of Block: ID

ID What is your participation code?

____

End of Block: ID

Start of Block: Background

Age How old are you?

____

X→

Gender What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Other, namely... (3) ____
- ○ I prefer not to answer (99)

X→

Education What is your highest completed education?

○ None (0)

○ I am still at school (1)

○ Elementary School (2)

○ High school (e.g., LTS, VMBO, Mavo, Havo, VWO, Household School, etc.) specify which: (3) ____

○ MBO (Intermediate Vocational Education, also for example MTS) (4)

○ HBO (Higher Vocational Education, also e.g. HTS) (5)

○ WO/University or higher (Scientific Education) (6)

○ Other, namely (7) ____

○ I prefer not to answer (99)

Nationality What nationality do you have?

▢ Dutch (1)

▢ Other, namely (2) ____

End of Block: Background

Start of Block: Perceived Stress

PSS Below are some statements about feelings people may experience. Please indicate how often you have had these feelings **in the past month**.

	Never (1)	Almost never (2)	Sometimes (3)	Fairly often (4)	Very often (5)
How often have you been upset because of something that happened unexpectedly? (PSS-4_1)	◯	◯	◯	◯	◯
How often have you felt that you were unable to control the important things in your life? (PSS-4_2)	◯	◯	◯	◯	◯
How often have you felt nervous and stressed? (PSS-4_3)	◯	◯	◯	◯	◯
How often have you felt confident about your ability to handle your personal problems? (PSS-4_4)	◯	◯	◯	◯	◯
How often have you felt that things were going your way? (PSS-4_5)	◯	◯	◯	◯	◯

How often have you found that you could not cope with all the things that you had to do? (PSS-4_6)	○	○	○	○	○
How often have you been able to control irritations in your life? (PSS-4_7)	○	○	○	○	○
How often have you felt that you were on top of things? (PSS-4_8)	○	○	○	○	○
How often have you been angered because of things that happened that were outside of your control? (PSS-4_9)	○	○	○	○	○
How often have you felt difficulties were piling up so high that you could not overcome them? (PSS-4_10)	○	○	○	○	○

End of Block: Perceived Stress

Start of Block: Stress Mindset

SMM Below are eight statements you can agree or disagree with. Please rate the extent to which you agree or disagree with the following statements.

	Strongly Disagree (0)	Disagree (1)	Neither Agree nor Disagree (2)	Agree (3)	Strongly Agree (4)
The effects of stress are negative and should be avoided. (SMM_1)	○	○	○	○	○
Experiencing stress facilitates my learning and growth. (SMM_2)	○	○	○	○	○
Experiencing stress depletes my health and vitality. (SMM_3)	○	○	○	○	○
Experiencing stress enhances my performance and productivity. (SMM_4)	○	○	○	○	○
Experiencing stress inhibits my learning and growth. (SMM_5)	○	○	○	○	○
Experiencing stress improves my health and vitality. (SMM_6)	○	○	○	○	○

Experiencing stress debilitates my performance and productivity. (SMM_7)	○	○	○	○	○
The effects of stress are positive and should be utilized. (SMM_8)	○	○	○	○	○

End of Block: Stress Mindset

Start of Block: Interoception

MAIA-2 Below you will find a list of statements. Please indicate how often each statement applies to you generally in daily life.

	Never (0)	Very Rarely (1)	Rarely (2)	Occasionally (3)	Frequently (4)	Alway (5)
When I am tense I notice where the tension is located in my body. (MAIA-2_1a)	○	○	○	○	○	○
I notice when I am uncomfortable in my body. (MAIA-2_2a)	○	○	○	○	○	○
I notice where in my body I am comfortable. (MAIA-2_3a)	○	○	○	○	○	○
I notice changes in my breathing, such as whether it slows down or speeds up. (MAIA-2_4a)	○	○	○	○	○	○
I ignore physical tension or discomfort until they become more severe. (MAIA-2_5bR)	○	○	○	○	○	○
I distract myself from sensations of discomfort. (MAIA-2_6bR)	○	○	○	○	○	○
When I feel pain or discomfort, I try to power through it. (MAIA-2_7bR)	○	○	○	○	○	○
I try to ignore pain. (MAIA-2_8bR)	○	○	○	○	○	○
I push feelings of discomfort away by focusing on something. (MAIA-2_9bR)	○	○	○	○	○	○

When I feel unpleasant body sensations, I occupy myself with something else so I don't have to feel. (MAIA-2_10bR)	○	○	○	○	○	○
When I feel physical pain, I become upset. (MAIA-2_11cR)	○	○	○	○	○	○
I start to worry that something is wrong if I feel any discomfort. (MAIA-2_12cR)	○	○	○	○	○	○
I can notice an unpleasant body sensation without worrying about it. (MAIA-2_13c)	○	○	○	○	○	○
I can stay calm and not worry when I have feelings of discomfort or pain. (MAIA-2_14c)	○	○	○	○	○	○
When I am in discomfort or pain I can't get it out of my mind. (MAIA-2_15cR)	○	○	○	○	○	○
I can pay attention to my breath without being distracted by things happening around me. (MAIA-2_16d)	○	○	○	○	○	○
I can maintain awareness of my inner bodily sensations even when there is a lot going on around me. (MAIA-2_17d)	○	○	○	○	○	○

When I am in conversation with someone, I can pay attention to my posture. (MAIA-2_18d)	○	○	○	○	○	○
I can return awareness to my body if I am distracted. (MAIA-2_19d)	○	○	○	○	○	○
I can refocus my attention from thinking to sensing my body. (MAIA-2_20d)	○	○	○	○	○	○
I can maintain awareness of my whole body even when a part of me is in pain or discomfort. (MAIA-2_21d)	○	○	○	○	○	○
I am able to consciously focus on my body as a whole. (MAIA-2_22d)	○	○	○	○	○	○
I notice how my body changes when I am angry. (MAIA-2_23e)	○	○	○	○	○	○
When something is wrong in my life I can feel it in my body. (MAIA-2_24e)	○	○	○	○	○	○
I notice that my body feels different after a peaceful experience. (MAIA-2_25e)	○	○	○	○	○	○

I notice that my breathing becomes free and easy when I feel comfortable. (MAIA-2_26e)	○	○	○	○	○	○
I notice how my body changes when I feel happy / joyful. (MAIA-2_27e)	○	○	○	○	○	○
When I feel overwhelmed I can find a calm place inside. (MAIA-2_28f)	○	○	○	○	○	○
When I bring awareness to my body I feel a sense of calm. (MAIA-2_29f)	○	○	○	○	○	○
I can use my breath to reduce tension. (MAIA-2_30f)	○	○	○	○	○	○
When I am caught up in thoughts, I can calm my mind by focusing on my body/breathing. (MAIA-2_31f)	○	○	○	○	○	○
I listen for information from my body about my emotional state. (MAIA-2_32g)	○	○	○	○	○	○
When I am upset, I take time to explore how my body feels. (MAIA-2_33g)	○	○	○	○	○	○
I listen to my body to inform me about what to do. (MAIA-2_34g)	○	○	○	○	○	○
I am at home in my body. (MAIA-2_35h)	○	○	○	○	○	○

I feel my body is a safe place. (MAIA-2_36h)	○	○	○	○	○	○
I trust my body sensations. (MAIA-2_37h)	○	○	○	○	○	○

End of Block: Interoception

Start of Block: Emotion Regulation

ERQ Please indicate the extent to which you agree or disagree with the statements below. You do so by choosing a response for each statement that corresponds to the following scale that ranges from 1 (*strongly disagree*) to 7 (*strongly agree*), where 4 is considered *neutral*.

	1 - strongly disagree (1)	2 (2)	3 (3)	4 - neutral (4)	5 (5)	6 (6)	7 - strongly agree (7)
When I want to feel more positive emotion (such as joy or amusement), I change what I'm thinking about. (ERQ_1)	○	○	○	○	○	○	○
I keep my emotions to myself. (ERQ_2)	○	○	○	○	○	○	○
When I want to feel less negative emotion (such as sadness or anger), I change what I'm thinking about. (ERQ_3)	○	○	○	○	○	○	○
When I am feeling positive emotions, I am careful not to express them. (ERQ_4)	○	○	○	○	○	○	○

When I'm faced with a stressful situation, I make myself think about it in a way that helps me stay calm. (ERQ_5)	○	○	○	○	○	○	○
I control my emotions by not expressing them. (ERQ_6)	○	○	○	○	○	○	○
When I want to feel more positive emotion, I change the way I'm thinking about the situation. (ERQ_7)	○	○	○	○	○	○	○
I control my emotions by changing the way I think about the situation I'm in. (ERQ_8)	○	○	○	○	○	○	○
When I am feeling negative emotions, I make sure not to express them. (ERQ_9)	○	○	○	○	○	○	○

When I want to feel less negative emotion, I change the way I'm thinking about the situation. (ERQ_10)	○	○	○	○	○	○	○

End of Block: Emotion Regulation

Start of Block: Health Anxiety

SHAI Please read each group of statements carefully and then select the one which best describes how you have felt over the past six months.

SHAI-1 1. I worry about my health.

○ Never (1)

○ Occasionally (2)

○ Much of the time (3)

○ Most of the time (4)

SHAI-2 2. Compared to other people my age I noticed aches and pains

○ less than most other people (1)

○ as much as most other people (2)

○ more than most other people (3)

○ in my body all the time (4)

SHAI-3 3. Which statement best describes your awareness of bodily sensations or changes?

- ◯ As a rule I am not aware of bodily sensations or changes (1)
- ◯ Sometimes aware (2)
- ◯ Often aware (3)
- ◯ Constantly aware (4)

SHAI-4 4. I can resist thoughts of illess

- ◯ Without a problem (1)
- ◯ Most of the time (2)
- ◯ I try to resist thoughts of illness but am often unable to do so (3)
- ◯ Thoughts of illness are so strong that I no longer even try to resist them (4)

SHAI-5 5. I am afraid of having a serious illness

- ◯ Not at all (1)
- ◯ Sometimes (2)
- ◯ Often (3)
- ◯ Always (4)

SHAI-6 6. I have images (mental pictures) of myself being ill.

- ◯ Never (1)
- ◯ Occasionally (2)
- ◯ Frequently (3)
- ◯ Constantly (4)

SHAI-7 7. I have difficulty taking my mind off thoughts about my health.

- ◯ Never (1)
- ◯ Sometimes (2)
- ◯ Often (3)
- ◯ Always - Nothing can take my mind off thoughts about my health (4)

SHAI-8 8. If my doctor tells me there is nothing wrong I am

- ◯ Lastingly relieved (1)
- ◯ Initially relieved but the worries sometimes return later (2)
- ◯ Initially relieved but the worries always return later (3)
- ◯ Not relieved if my doctor tells me there is nothing wrong (4)

SHAI-9 When I hear about an illness I think I have it myself.

- ◯ Never (1)
- ◯ Sometimes (2)
- ◯ Often (3)
- ◯ Always (4)

SHAI-10 10. If I have a bodily sensation or change I wonder what it means.

- ◯ Rarely (1)
- ◯ Often (2)
- ◯ Always (3)
- ◯ If I have a bodily sensation or change I must know what it means (4)

SHAI-11 11. I usually feel my risk of developing a serious illness is

- ◯ Very low (1)
- ◯ Fairly low (2)
- ◯ Moderate (3)
- ◯ High (4)

SHAI-12 12. I think I have a serious illness.

- ◯ Never (1)
- ◯ Sometimes (2)
- ◯ Often (3)
- ◯ Usually (4)

SHAI-13 13. If I notice an unexplained bodily sensation I

- ◯ Don’t find it difficult to think about other things (1)
- ◯ Sometimes find it difficult to think about other things (2)
- ◯ Often find it difficult to think about other things (3)
- ◯ Always find it difficult to think about other things (4)

SHAI-14 14. My family or friends would say I

- ◯ Do not worry enough about my health (1)
- ◯ Have a normal attitude to my health (2)
- ◯ Worry too much about my health (3)
- ◯ Am a hypochondriac (4)

End of Block: Health Anxiety

Start of Block: Personality

Personality Here are a number of characteristics that may or may not apply to you. For example, do you agree that you are someone who likes to spend time with others? Please indicate for each statement the extent to which you agree or disagree with that statement. There are no right or wrong answers, your own opinion counts. **I am someone who . . .**

	Disagree strongly (1)	Disagree (2)	Neutral; no opinion (3)	Agree (4)	Agree strongly (5)
Tends to be quiet (Personality_1_Er)	○	○	○	○	○
Is compassionate, has a soft heart (Personality_2_A)	○	○	○	○	○
Tends to be disorganized (Personality_3_Cr)	○	○	○	○	○
Worries a lot (Personality_4_N)	○	○	○	○	○
Is fascinated by art, music, or literature (Personality_5_O)	○	○	○	○	○
Is dominant, acts as a leader (Personality_6_E)	○	○	○	○	○
Is sometimes rude to others (Personality_7_Ar)	○	○	○	○	○
Has difficulty getting started on tasks (Personality_8_Cr)	○	○	○	○	○
Tends to feel depressed, blue (Personality_9_N)	○	○	○	○	○
Has little interest in abstract Ideas (Personality_10_Or)	○	○	○	○	○
Is full of energy (Personality_11_E)	○	○	○	○	○
Assumes the best about people (Personality_12_A)	○	○	○	○	○
Is reliable, can always be counted on (Personality_13_C)	○	○	○	○	○

Is emotionally stable, not easily upset (Personality_14_Nr)	○	○	○	○	○
Is original, comes up with new Ideas (Personality_15_O)	○	○	○	○	○

End of Block: Personality

MML-StressWearables - FollowUpAFTERwearable

Start of Block: ID

ID What is your participation code?

____

End of Block: ID

Start of Block: Perceived Stress

PSS Below are some statements about feelings people may experience. Please indicate how often you have had these feelings **in the last week**.

	Never (1)	Almost never (2)	Sometimes (3)	Fairly often (4)	Very often (5)
How often have you been upset because of something that happened unexpectedly? (PSS-4_1)	○	○	○	○	○
How often have you felt that you were unable to control the important things in your life? (PSS-4_2)	○	○	○	○	○
How often have you felt nervous and stressed? (PSS-4_3)	○	○	○	○	○
How often have you felt confident about your ability to handle your personal problems? (PSS-4_4)	○	○	○	○	○
How often have you felt that things were going your way? (PSS-4_5)	○	○	○	○	○

How often have you found that you could not cope with all the things that you had to do? (PSS-4_6)	○	○	○	○	○
How often have you been able to control irritations in your life? (PSS-4_7)	○	○	○	○	○
How often have you felt that you were on top of things? (PSS-4_8)	○	○	○	○	○
How often have you been angered because of things that happened that were outside of your control? (PSS-4_9)	○	○	○	○	○
How often have you felt difficulties were piling up so high that you could not overcome them? (PSS-4_10)	○	○	○	○	○

End of Block: Perceived Stress

Start of Block: Stress Mindset

SMM Below are eight statements you can agree or disagree with. Please rate the extent to which you agree or disagree with the following statements.

	Strongly Disagree (0)	Disagree (1)	Neither Agree nor Disagree (2)	Agree (3)	Strongly Agree (4)
The effects of stress are negative and should be avoided. (SMM_1)	○	○	○	○	○
Experiencing stress facilitates my learning and growth. (SMM_2)	○	○	○	○	○
Experiencing stress depletes my health and vitality. (SMM_3)	○	○	○	○	○
Experiencing stress enhances my performance and productivity. (SMM_4)	○	○	○	○	○
Experiencing stress inhibits my learning and growth. (SMM_5)	○	○	○	○	○
Experiencing stress improves my health and vitality. (SMM_6)	○	○	○	○	○

Experiencing stress debilitates my performance and productivity. (SMM_7)	○	○	○	○	○
The effects of stress are positive and should be utilized. (SMM_8)	○	○	○	○	○

End of Block: Stress Mindset

Start of Block: Health Anxiety

SHAI Please read each group of statements carefully and then select the one which best describes how you have felt over the **last week**.

SHAI-1 1. I worry about my health.

○ Never (1)

○ Occasionally (2)

○ Much of the time (3)

○ Most of the time (4)

SHAI-2 2. Compared to other people my age I noticed aches and pains

○ less than most other people (1)

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○ in my body all the time (4)

SHAI-3 3. Which statement best describes your awareness of bodily sensations or changes?

- ◯ As a rule I am not aware of bodily sensations or changes (1)
- ◯ Sometimes aware (2)
- ◯ Often aware (3)
- ◯ Constantly aware (4)

SHAI-4 4. I can resist thoughts of illess

- ◯ Without a problem (1)
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- ◯ I try to resist thoughts of illness but am often unable to do so (3)
- ◯ Thoughts of illness are so strong that I no longer even try to resist them (4)

SHAI-5 5. I am afraid of having a serious illness

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SHAI-8 8. If my doctor tells me there is nothing wrong I am

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SHAI-9 When I hear about an illness I think I have it myself.

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- If I have a bodily sensation or change I must know what it means (4)

SHAI-11 11. I usually feel my risk of developing a serious illness is

- Very low (1)
- Fairly low (2)
- Moderate (3)
- High (4)

SHAI-12 12. I think I have a serious illness.

- Never (1)
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- Often (3)
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SHAI-13 13. If I notice an unexplained bodily sensation I

- Don't find it difficult to think about other things (1)
- Sometimes find it difficult to think about other things (2)
- Often find it difficult to think about other things (3)
- Always find it difficult to think about other things (4)

SHAI-14 14. My family or friends would say I

- Do not worry enough about my health (1)
- Have a normal attitude to my health (2)
- Worry too much about my health (3)
- Am a hypochondriac (4)

End of Block: Health Anxiety

MML-StressWearables - FollowUpNOwearable

Start of Block: ID

ID What is your participation code?

____

End of Block: ID

Start of Block: Perceived Stress

PSS Below are some statements about feelings people may experience. Please indicate how often you have had these feelings **in the last week**.

	Never (1)	Almost never (2)	Sometimes (3)	Fairly often (4)	Very often (5)
How often have you been upset because of something that happened unexpectedly? (PSS-4_1)	○	○	○	○	○
How often have you felt that you were unable to control the important things in your life? (PSS-4_2)	○	○	○	○	○
How often have you felt nervous and stressed? (PSS-4_3)	○	○	○	○	○
How often have you felt confident about your ability to handle your personal problems? (PSS-4_4)	○	○	○	○	○
How often have you felt that things were going your way? (PSS-4_5)	○	○	○	○	○

How often have you found that you could not cope with all the things that you had to do? (PSS-4_6)	○	○	○	○	○
How often have you been able to control irritations in your life? (PSS-4_7)	○	○	○	○	○
How often have you felt that you were on top of things? (PSS-4_8)	○	○	○	○	○
How often have you been angered because of things that happened that were outside of your control? (PSS-4_9)	○	○	○	○	○
How often have you felt difficulties were piling up so high that you could not overcome them? (PSS-4_10)	○	○	○	○	○

End of Block: Perceived Stress

Start of Block: Stress Mindset

SMM Below are eight statements you can agree or disagree with. Please rate the extent to which you agree or disagree with the following statements.

	Strongly Disagree (0)	Disagree (1)	Neither Agree nor Disagree (2)	Agree (3)	Strongly Agree (4)
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Experiencing stress facilitates my learning and growth. (SMM_2)	○	○	○	○	○
Experiencing stress depletes my health and vitality. (SMM_3)	○	○	○	○	○
Experiencing stress enhances my performance and productivity. (SMM_4)	○	○	○	○	○
Experiencing stress inhibits my learning and growth. (SMM_5)	○	○	○	○	○
Experiencing stress improves my health and vitality. (SMM_6)	○	○	○	○	○

Experiencing stress debilitates my performance and productivity. (SMM_7)	○	○	○	○	○
The effects of stress are positive and should be utilized. (SMM_8)	○	○	○	○	○

End of Block: Stress Mindset

Start of Block: Health Anxiety

SHAI Please read each group of statements carefully and then select the one which best describes how you have felt over the **last week**.

SHAI-1 1. I worry about my health.

○ Never (1)

○ Occasionally (2)

○ Much of the time (3)

○ Most of the time (4)

SHAI-2 2. Compared to other people my age I noticed aches and pains

○ less than most other people (1)

○ as much as most other people (2)

○ more than most other people (3)

○ in my body all the time (4)

SHAI-3 3. Which statement best describes your awareness of bodily sensations or changes?

- As a rule I am not aware of bodily sensations or changes (1)
- Sometimes aware (2)
- Often aware (3)
- Constantly aware (4)

SHAI-4 4. I can resist thoughts of illess

- Without a problem (1)
- Most of the time (2)
- I try to resist thoughts of illness but am often unable to do so (3)
- Thoughts of illness are so strong that I no longer even try to resist them (4)

SHAI-5 5. I am afraid of having a serious illness

- Not at all (1)
- Sometimes (2)
- Often (3)
- Always (4)

SHAI-6 6. I have images (mental pictures) of myself being ill.

- Never (1)
- Occasionally (2)
- Frequently (3)
- Constantly (4)

SHAI-7 7. I have difficulty taking my mind off thoughts about my health.

- Never (1)
- Sometimes (2)
- Often (3)
- Always - Nothing can take my mind off thoughts about my health (4)

SHAI-8 8. If my doctor tells me there is nothing wrong I am

- Lastingly relieved (1)
- Initially relieved but the worries sometimes return later (2)
- Initially relieved but the worries always return later (3)
- Not relieved if my doctor tells me there is nothing wrong (4)

SHAI-9 When I hear about an illness I think I have it myself.

- Never (1)
- Sometimes (2)
- Often (3)
- Always (4)

SHAI-10 10. If I have a bodily sensation or change I wonder what it means.

- ◯ Rarely (1)
- ◯ Often (2)
- ◯ Always (3)
- ◯ If I have a bodily sensation or change I must know what it means (4)

SHAI-11 11. I usually feel my risk of developing a serious illness is

- ◯ Very low (1)
- ◯ Fairly low (2)
- ◯ Moderate (3)
- ◯ High (4)

SHAI-12 12. I think I have a serious illness.

- ◯ Never (1)
- ◯ Sometimes (2)
- ◯ Often (3)
- ◯ Usually (4)

SHAI-13 13. If I notice an unexplained bodily sensation I

- ◯ Don’t find it difficult to think about other things (1)
- ◯ Sometimes find it difficult to think about other things (2)
- ◯ Often find it difficult to think about other things (3)
- ◯ Always find it difficult to think about other things (4)

SHAI-14 14. My family or friends would say I

- Do not worry enough about my health (1)
- Have a normal attitude to my health (2)
- Worry too much about my health (3)
- Am a hypochondriac (4)

End of Block: Health Anxiety

Appendix D
M-path questions

Morning questionnaire

1.1. Approximately how long did you sleep

1.1.1. 00 to 23 hours can be chosen on one axis and 00 to 59 on another.

1.2. How would you rate the quality of your sleep

1.2.1. A rating from 0 to 100 can be indicated using a slider. On the left side is very bad, on the right side very good.

1.3. Yesterday I used the following products:

1.3.1. Caffeine

1.3.2. Nicotine

1.3.3. Alcohol

1.3.4. Cannabis

1.3.5. Other drugs, namely: ...

1.3.6. None of the above

Daily core

1.1. At the moment my positive feelings are

1.1.1. A rating from 0 to 100 can be indicated using a slider. On the left side is not strong at all, on the right side is very strong.

1.2. At the moment my negative feelings are

1.2.1. A rating from 0 to 100 can be indicated using a slider. On the left side is not strong at all, on the right side is very strong.

1.3. At the moment I feel stressed

1.3.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.4. At the moment I feel tense

1.4.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.5. Right now I feel energized

1.5.1. A rating from 0 to 100 can be indicated using a slider. There is no text on the sides. In the middle is a battery that gets fuller as a higher energy score is indicated.

1.6. Since the previous questionnaire, to what extent have you been mentally overloaded by too much information? (e.g., during a call at home or work, while multitasking, etc.)

1.6.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

Evening questionnaire

1.1. At the moment my positive feelings are

1.1.1. A rating from 0 to 100 can be indicated using a slider. On the left side is not strong at all, on the right side is very strong.

1.2. At the moment my negative feelings are

1.2.1. A rating from 0 to 100 can be indicated using a slider. On the left side is not strong at all, on the right side is very strong.

1.3. At the moment I feel stressed

1.3.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.4. At the moment I feel tense

1.4.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.5. Right now I feel energized

1.5.1. A rating from 0 to 100 can be indicated using a slider. There is no text on the sides. In the middle is a battery that gets fuller as a higher energy score is indicated.

1.6. Since the previous questionnaire, to what extent have you been mentally overloaded by too much information? (e.g., during a call at home or work, while multitasking, etc.)

1.6.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.7. How was your day today?

1.7.1. A rating from 0 to 100 can be indicated using a slider. On the left side it says not at all, on the right side it says very much.

1.8. How was your day today

1.8.1. A rating from 0 to 100 can be indicated using a slider. On the left side is relaxed, on the right side is stressful.

1.9. Describe your day: What was the most unpleasant situation?

1.9.1. Do you want to type or record this?

1.9.1.1. Type in

1.9.1.2. Recording

1.10. Describe your day: What was the most pleasant situation?

1.10.1. Do you want to type or record this?

1.10.1.1. Type in

1.10.1.2. Recording

1.11. Today I felt physical discomfort (e.g. fatigue, flu, headache, back pain, ringing in the ears, tension, hay fever, period pain)

1.11.1. Yes

1.11.2. No

1.12. Today I felt that I had control over the important things in my life

1.12.1. A dotted line with five dots can be seen with options 0 through 4. On the left is never said, on the right it says very often.

1.13. Today I felt confident to deal with personal problems

1.13.1. A dotted line with five dots can be seen with options 0 through 4. On the left is never said, on the right it says very often.

1.14. Today I had the feeling that things were going the way I wanted them to

1.14.1. A dotted line with five dots can be seen with options 0 through 4. On the left is never said, on the right it says very often.

1.15. Today I felt like difficulties were piling up so high that I couldn't handle them anymore

1.15.1. A dotted line with five dots can be seen with options 0 through 4. On the left is never said, on the right it says very often.

1.16. Did you experience anything else stressful today that you were unable to indicate? For example, because it was not an unpleasant or pleasant situation?

1.16.1. A large white compartment in which you can type

1.16.2. Skip this question...

Appendix E

Informed consent

Thank you for participating in our study. This study investigates the relationship between stress feedback from wearables, perceived stress, personality and health anxiety. Participating in this study is voluntary and it is possible to withdraw at any time during the study without providing a reason. The questionnaires consist of several questions about stress, relaxation, interoception, health anxiety, emotion regulation and personality. In the first questionnaire, there will be some questions about demographics. Please answer all questions as honestly as possible.

Your participation will take two weeks in which you are expected to fill out five questionnaires daily. With an additional questionnaire at the start of the first week, at the start of the second week and the end of the second week.

All data collected will be anonymised and will only be seen by the researchers, but cannot be traced back to you. This study is part of a bigger research project. Therefore, your anonymised data could also be used in other studies regarding stress feedback from wearables. The data will be stored following the guidelines of the University of Twente. If there are any questions or remarks, feel free to contact the researchers:

Anna Fyntiki: a.fyntiki@student.utwente.nl
Toya Ropers: t.ropers@student.utwente.nl

Supervisor:
Matthijs Noordzij: m.l.noordzij@utwente.nl

I read the informed consent, and agree to participate in this study. My results can be used for the purpose of the study and the research project of which this study is part.

○ *Yes*

○ *No*

Appendix F
Order condition

In this appendix additional descriptives, visualisations and model output are presented. All of them include the order wearable as a predictor, so whether the wearable was worn in the first or second week. As these analyses are not central to the research questions they were put in the appendix. However, they do offer insight into this other aspect. No significant interaction between the condition and order was observed in any of the models.

Descriptives with order group

Table F1

PSS Descriptives per Condition and Order Group

Condition	Order group	N	Min	Max	Mean	SD
Baseline	Watch Week 1	37	16	35	24.7	5.10
Baseline	Watch Week 2	33	17	38	26.3	5.82
NoWear	Watch Week 1	37	11	35	21.7	4.67
NoWear	Watch Week 2	33	14	35	23.8	5.72
Wear	Watch Week 1	37	15	40	23.1	5.56
Wear	Watch Week 2	33	13	37	23.5	5.97

Note. N= number of participants, SD = standard deviation, Min = minimum score, Max = maximum score

Table F2

SHAI Descriptives per Condition and Order Group

Time	Order group	N	Min	Max	Mean	SD
Baseline	Watch Week 1	37	17	38	23.6	5.34
Baseline	Watch Week 2	33	18	44	25.3	6.05
NoWear	Watch Week 1	37	14	39	22.5	5.33
NoWear	Watch Week 2	33	17	45	24.5	5.90
Wear	Watch Week 1	37	16	39	23.4	5.22
Wear	Watch Week 2	33	15	33	23.4	4.76

Note. N= number of participants, SD = standard deviation, Min = minimum score, Max = maximum score

Visualisations with order group

Figure F1

Mean trajectories of PSS-10 and SHAI-14 scores over Time by Wearable Order group

Figure F2

Boxplots showing the Distribution of PSS and SHAI scores by Time and Order group

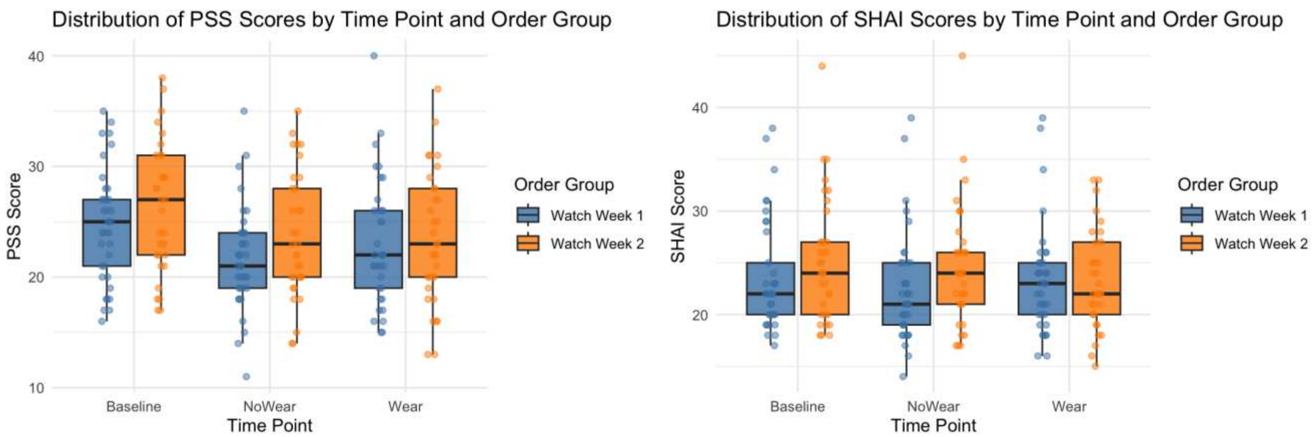
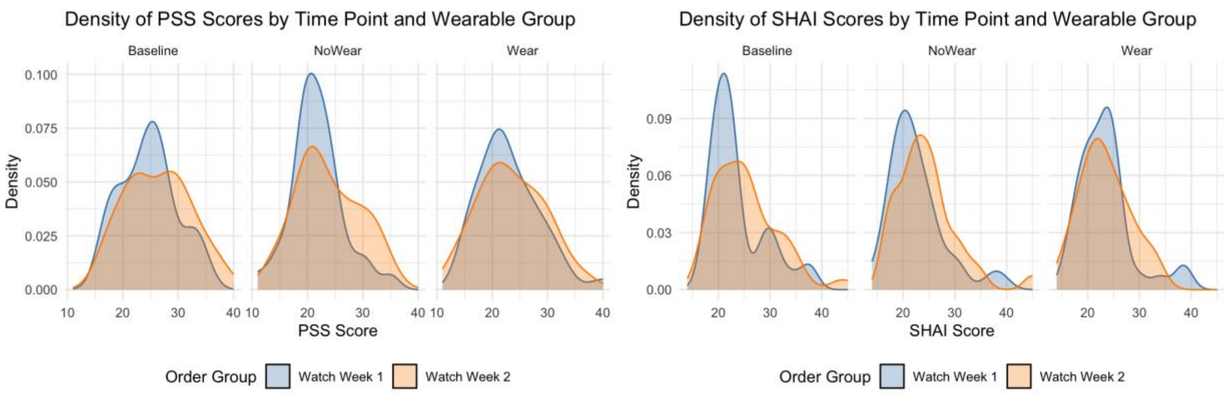


Figure F3

Density plots of PSS and SHAI scores by condition



Linear Mixed Models with Order

Table F3

(N=210 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept	24.68	0.90	103.68	27.43	<.001
Condition: NoWear	-2.97	0.70	136	-4.24	<.001
Condition: Wear	-1.59	0.70	136	-2.27	.025
Wearable Order	1.63	1.31	103.68	1.24	.217
Condition: NoWear x Order	0.43	1.02	136	0.42	.677
Condition: Wear x Order	-1.22	1.02	136	-1.20	.234

Note. Reference category for condition is Baseline and for group is Watch Week 1.

Table F4

Fixed Effect Estimates from Linear Mixed Model Predicting SHAI Scores

(N=210 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept	23.59	0.89	90.63	26.37	<.001
Condition: NoWear	-1.08	0.58	136	-1.87	.064
Condition: Wear	-0.24	0.58	136	-0.42	.675
Wearable Order	1.71	1.30	90.63	1.31	.193
Condition: NoWear x Order	0.26	0.84	136	0.31	.756
Condition: Wear x Order	-1.64	0.84	136	-1.94	.054

Note. Reference category for condition is Baseline and for group is Watch Week 1.

Table F5

Fixed Effect Estimates from Linear Mixed Model Predicting Average Ambulatory Stress

(N=140 observations, 70 Participants)

Predictor	**Estimate *(b)***	**SE**	**df**	***t***	***p***
Intercept	24.03	5.05	82.29	4.76	<.001
Week 2	-3.71	3.13	68.00	-1.19	.239
Order (1= wearable in week 2)	-0.99	3.28	82.29	-0.30	.764
Week 2 + Order	1.3	2.03	68.00	0.64	.524

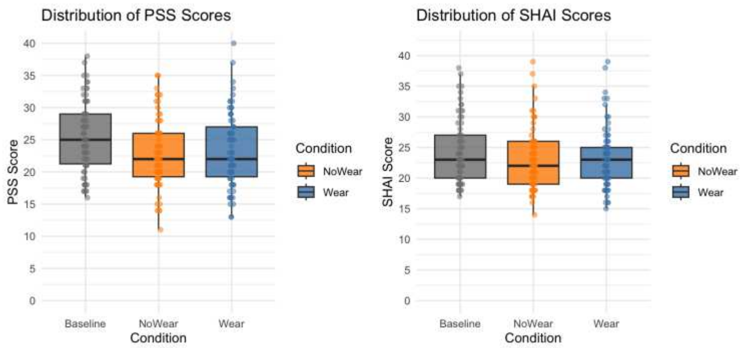
Note. Reference category for week is Week 1.

Appendix G

Additional Visualisations of PSS and SHAI Scores as well as ESM

Figure G1

Boxplots Showing the Distribution of PSS and SHAI scores by Condition



Note. The distribution of PSS and SHAI scores across the three conditions, as well as mean and variability. This graph goes from the theoretical minimum to the theoretical maximum of both questionnaires.

Figure G2

Density plots of PSS and SHAI scores by Condition

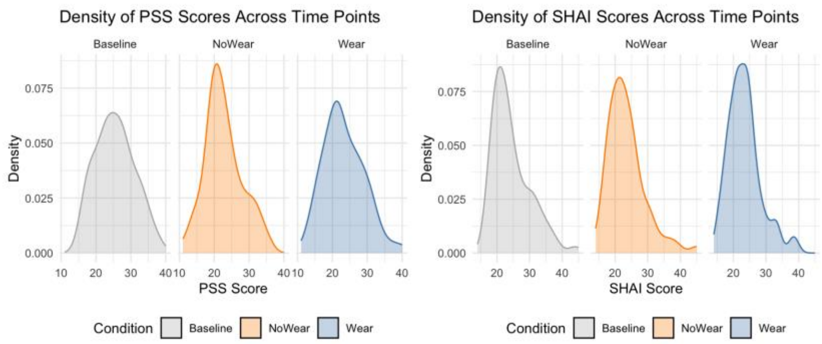


Figure G3

Histogram of PSS of all conditions

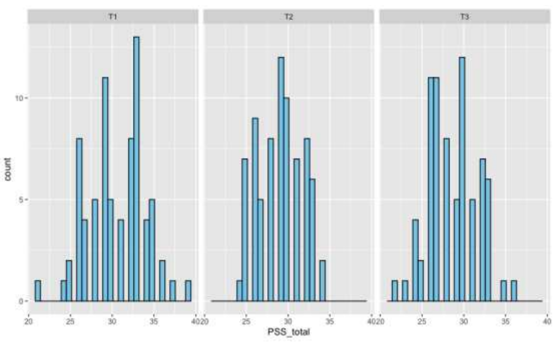
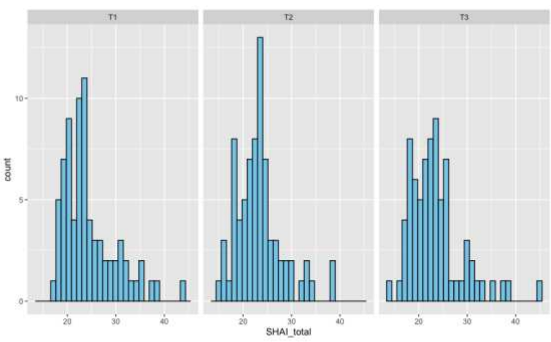


Figure G4

Histogram of SHAI of all conditions

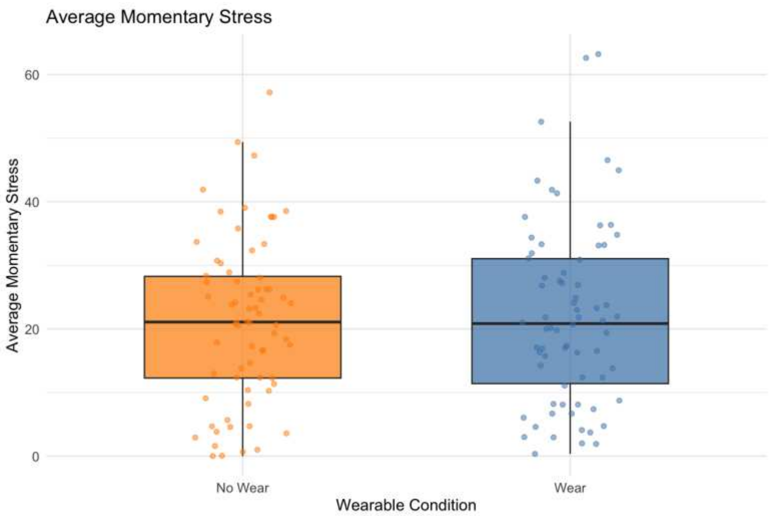


Note. The number of participants per PSS total scores across the three conditions. T1 is baseline, T2 is wear and T3 no wear.

Note. The number of participants per SHAI total scores across the three conditions. T1 is baseline, T2 is wear and T3 no wear.

Figure G5

Boxplot showing the Weekly Average Momentary Stress Scores by Wear Condition



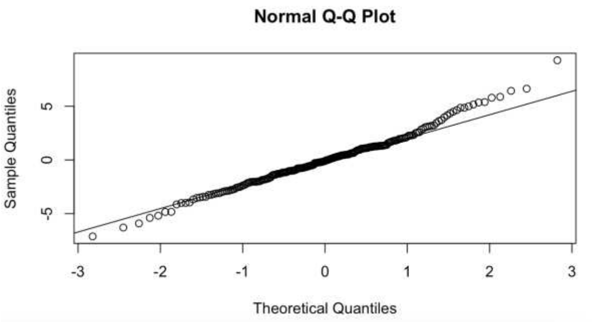
Appendix H

Parametric assumptions tests

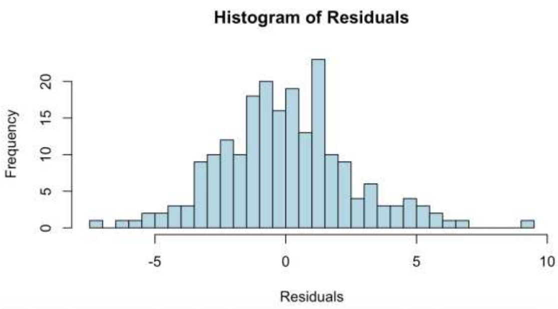
PSS

Check normality of residuals:

QQ-Plot

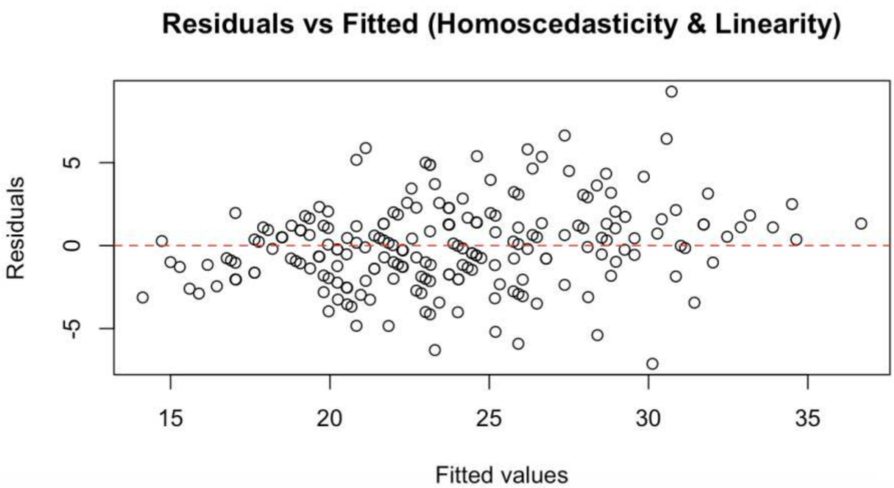


Histogram



Check Linearity and Homoscedasticity (residuals vs fitted values)

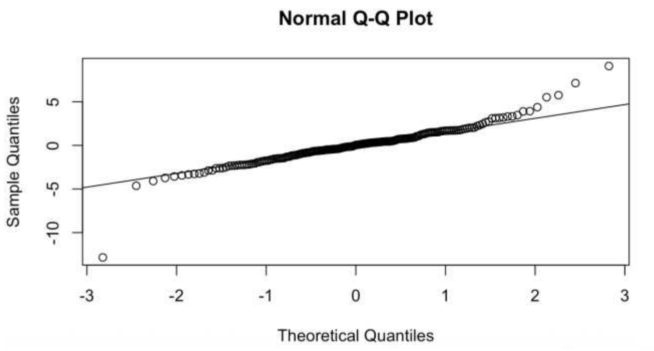
Scatter plot



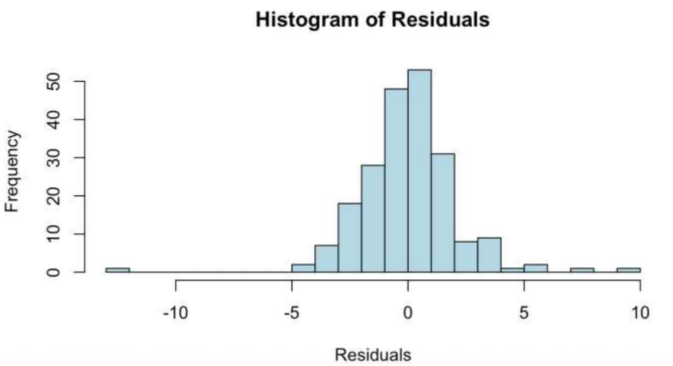
SHAI

Check normality of residuals:

QQ-Plot

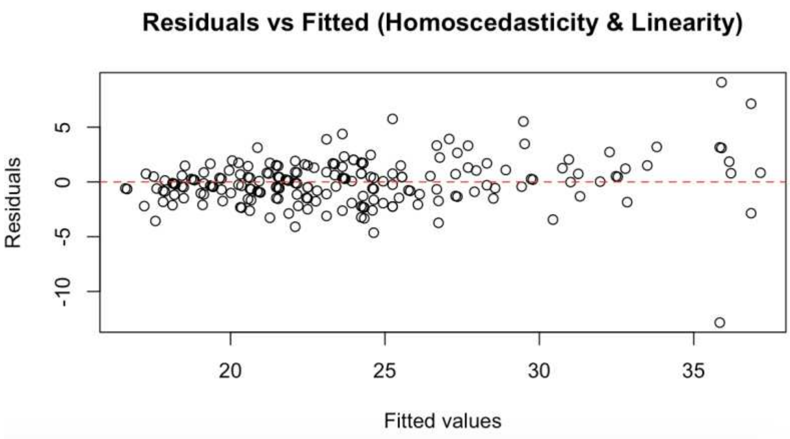


Histogram



Check Linearity and Homoscedasticity (residuals vs fitted values)

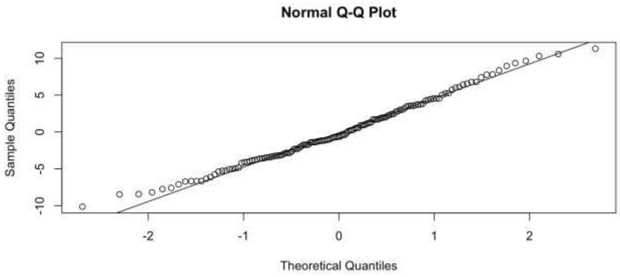
Scatter plot



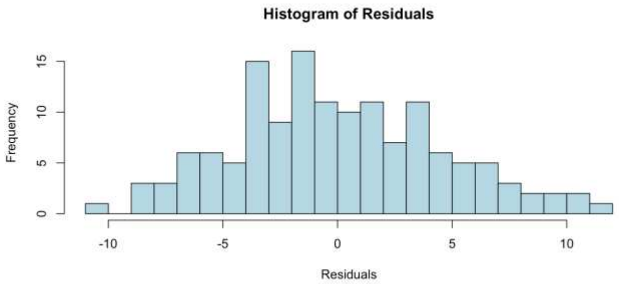
ESM

Check normality of residuals:

QQ-Plot

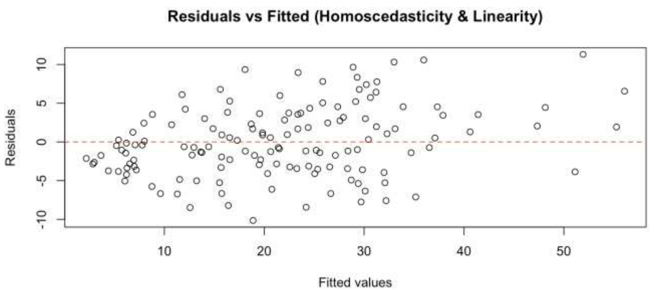


Histogram



Check Linearity and Homoscedasticity (residuals vs fitted values)

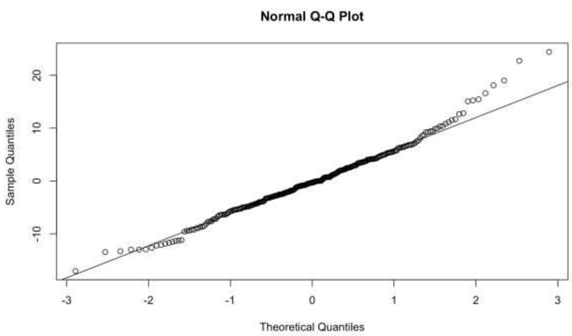
Scatter plot



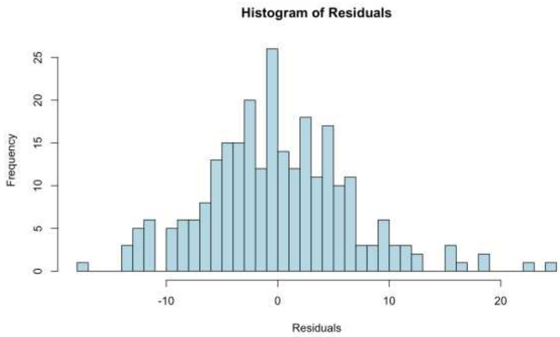
PSS and ESM

Check normality of residuals:

QQ-Plot

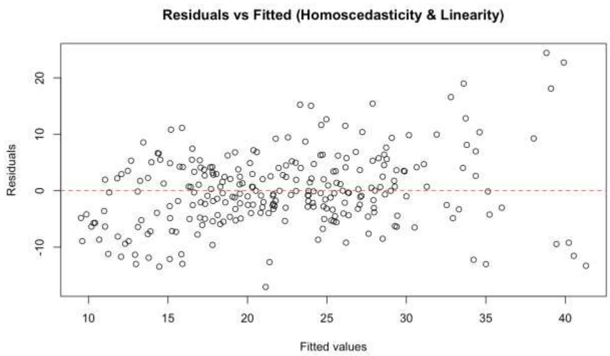


Histogram



Check Linearity and Homoscedasticity (residuals vs fitted values)

Scatter plot



Appendix I

R-script

```
#Data analyses stress wearables

# set up R-studio
library(tidyverse)
library(dplyr)
library(readxl)
library(fuzzyjoin)
library(ggplot2)
library(tidyr)
library(stringr)
library(lubridate)
library(broom)
library(psych)
library(CTT)
library(ltm)
library(MASS)
library(haven)
library(readxl)
library(lme4)
library(emmeans)
library(lmerTest)
library(patchwork)
library(car)
library(rstatix)

#set working directory
setwd("~/Desktop")

#1 Qualtrics

#1.1 Transfer Qualtrics Data Set
```

```
dataQualtricsAll <- read_sav("~/Desktop/Wearables_allmerged_050525.sav")
read_sps

#delete underage people
Qualtrics_relevant <- dataQualtricsAll[dataQualtricsAll$Age >= 18 ,]

#Selecting important columns of ID, PSS and SHAI
Qualtrics_relevant <- Qualtrics_relevant %>% dplyr::select(ID,
                                            PSS_4_1:PSS_4_10,PSS_4_1_FUW:PSS_4_10_FUW,
                                            PSS_4_1_FUNO:PSS_4_10_FUNO,SHAI_1:SHAI_14,

SHAI_1_FUW:SHAI_14_FUW,SHAI_1_FUNO:SHAI_14_FUNO)

#add m-path data
mPath <- read_excel("Data M-Path010525.xlsx")

#only the relavant
mPath_relevant <- mPath %>% dplyr::select(`Original
Order`:Occasion,alias,questionListName,
                              stressed_sliderNeutralPos)

#create data sets per occasion
mPath_1 <- mPath_relevant %>% filter(Occasion =="1")
mPath_2 <- mPath_relevant %>% filter(Occasion =="2")
mPath_3 <- mPath_relevant %>% filter(Occasion =="3")
mPath_4 <- mPath_relevant %>% filter(Occasion =="4")



#create order varibale#
##so merging the questionnaires

#make short version of m-path 1
mPath1_short <- mPath_1 %>%
  filter(Week == 1, Day == 1)
```

```
#rename the ID to alias in qualtrics order
Qualtrics_relevant_order <- Qualtrics_relevant %>% rename(alias = ID)

#merge qualtrics and mpath for order condition
Qualtrics_relevant_order <- Qualtrics_relevant_order %>%
  left_join(
    mPath1_short%>% dplyr::select(alias, `Order (1=wearable in first week, 2=wearable in 2nd week)`),
    by = "alias"
  )

#make it a dummy variable as that is easiest for linear mixed models, which i will do later
#does not want to make it a dummy variable, uses 1s (wearable in 1st week) and 2s (wearable in 2nd week)
#I will a a dummy variable in a new coloum wiht 0s (werable in 1st week) and 1s (wearable in 2nd week)
Qualtrics_relevant_order <- Qualtrics_relevant_order %>%
  mutate(wearable_dummy = if_else(`Order (1=wearable in first week, 2=wearable in 2nd week)` == 1, 0L, 1L))
#now I have created a coloum with the order 1 or 2 and an extra dummy variable with 0 and 1


#####Qualtrics Analyis####

#show missing values
Qualtrics_relevant_order[!complete.cases(Qualtrics_relevant_order), ]

#delete people with missing rows
Qualtrics_relevant_order_clean <- na.omit(Qualtrics_relevant_order)
#there is 70 people left now

#show any duplicates
Qualtrics_relevant_order_clean %>% count(alias) %>% filter(n > 1)
```

```
#no duplicates

###demographic analysis###
#rows to remove as it is still 96
removed_aliases <- setdiff(dataQualtricsAll$ID, Qualtrics_relevant_order_clean$alias)

removed_aliases <- setdiff(
  as.character(dataQualtricsAll$ID),
  as.character(Qualtrics_relevant_order_clean$alias)
)

str(removed_aliases)

str(dataQualtricsAll$ID)

removed_rows <- dataQualtricsAll %>%
  filter(ID %in% removed_aliases)

removed_ids <- removed_rows$ID

#making the demographics data set
Qualtics_demographics_clean <- dataQualtricsAll[ !(dataQualtricsAll$ID %in%
removed_ids), ]

#only including the demographics
Qualtics_demographics_clean <- Qualtics_demographics_clean %>%
dplyr::select(ID,Age:Nationality_2_TEXT)

#start of demographic analyses
##Gender
table(Qualtics_demographics_clean$Gender)

##Age
# there is an empty string "", so omit that for this
```

```
#and age was read as a character, so change to numeric

# Replace the empty string with NA
Qualtics_demographics_clean$Age[Qualtics_demographics_clean$Age == ""] <- NA
# Convert to numeric
Qualtics_demographics_clean$Age <- as.numeric(Qualtics_demographics_clean$Age)

summary(Qualtics_demographics_clean$Age)
table(Qualtics_demographics_clean$Age)
mean_age <- mean(Qualtics_demographics_clean$Age, na.rm = TRUE)
sd_age <- sd(Qualtics_demographics_clean$Age, na.rm = TRUE)
mean_age
sd_age

##Nationality
table(Qualtics_demographics_clean$Nationality_1)
table(Qualtics_demographics_clean$Nationality_2)

table(Qualtics_demographics_clean$Nationality_2_TEXT)

##Education
table(Qualtics_demographics_clean$Education)
education_3_table <- table(Qualtics_demographics_clean$Education_3_TEXT)
education_3_table
#figure out what the different numbers mean
unique(Qualtics_demographics_clean$Education)

# reverse code PSS scores
max_score <- 5
min_score <- 1

Qualtrics_relevant_order_clean_Rev <- Qualtrics_relevant_order_clean %>%
  mutate(
    PSS_4_4 = (max_score + min_score) - PSS_4_4,
```

```
    PSS_4_5 = (max_score + min_score) - PSS_4_5,
    PSS_4_7 = (max_score + min_score) - PSS_4_7,
    PSS_4_8 = (max_score + min_score) - PSS_4_8,
    PSS_4_4_FUW = (max_score + min_score) - PSS_4_4_FUW,
    PSS_4_5_FUW = (max_score + min_score) - PSS_4_5_FUW,
    PSS_4_7_FUW = (max_score + min_score) - PSS_4_7_FUW,
    PSS_4_8_FUW = (max_score + min_score) - PSS_4_8_FUW,
    PSS_4_4_FUNO = (max_score + min_score) - PSS_4_4_FUNO,
    PSS_4_5_FUNO = (max_score + min_score) - PSS_4_5_FUNO,
    PSS_4_7_FUNO = (max_score + min_score) - PSS_4_7_FUNO,
    PSS_4_8_FUNO = (max_score + min_score) - PSS_4_8_FUNO,
  )

#Adding total coloums for PSS and SHAI at all three time points
#for PSS
Qualtrics_relevant_order_clean_Rev$pss_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("PSS_4_", 1:10)], na.rm = TRUE)

Qualtrics_relevant_order_clean_Rev$pssFUW_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("PSS_4_", 1:10, "_FUW")], na.rm =
TRUE)

Qualtrics_relevant_order_clean_Rev$pssFUNO_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("PSS_4_", 1:10, "_FUNO")], na.rm =
TRUE)

#and for SHAI
Qualtrics_relevant_order_clean_Rev$Shai_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("SHAI_", 1:14)], na.rm = TRUE)

Qualtrics_relevant_order_clean_Rev$ShaiFUW_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("SHAI_", 1:14, "_FUW")], na.rm =
TRUE)
```

```
Qualtrics_relevant_order_clean_Rev$ShaiFUNO_total <-
rowSums(Qualtrics_relevant_order_clean_Rev[, paste0("SHAI_", 1:14, "_FUNO")], na.rm =
TRUE)

##check reliability
#do cronbachs alpha for PSS and SHAI, for each time individually
#PSS
pss_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 2:11])
print(pss_alpha_result)
#PSS_FUW
pss_FUW_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 12:21])
print(pss_FUW_alpha_result)
#PSS_FUNO
pss_FUNO_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 22:31])
print(pss_FUNO_alpha_result)

#SHAI
shai_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 32:45])
print(shai_alpha_result)
#SHAI_FUW
shai_FUW_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 46:59])
print(shai_FUW_alpha_result)
#SHAI_FUNO
shai_FUNO_alpha_result <- cronbach.alpha(Qualtrics_relevant_order_clean_Rev[, 60:73])
print(shai_FUNO_alpha_result)

#######
#make long data
##shape PSS into long format
PSS_long <- Qualtrics_relevant_order_clean_Rev %>%
  dplyr::select(alias, pss_total, pssFUW_total, pssFUNO_total,wearable_dummy) %>%
  tidyr::pivot_longer(
    cols = c(pss_total, pssFUW_total, pssFUNO_total),
    names_to = "Time",
```

```
    values_to = "PSS_total"
  ) %>%
  dplyr::mutate(Time = dplyr::case_when(
    Time == "pss_total" ~ "Baseline",
    Time == "pssFUW_total" ~ "Wear",
    Time == "pssFUNO_total" ~ "NoWear"
  ))

##shape SHAI into long format
SHAI_long <- Qualtrics_relevant_order_clean_Rev %>%
  dplyr::select(alias, Shai_total, ShaiFUW_total, ShaiFUNO_total, wearable_dummy) %>%
  tidyr::pivot_longer(
    cols = c(Shai_total, ShaiFUW_total, ShaiFUNO_total),
    names_to = "Time",
    values_to = "SHAI_total"
  ) %>%
  dplyr::mutate(Time = dplyr::case_when(
    Time == "Shai_total" ~ "Baseline",
    Time == "ShaiFUW_total" ~ "Wear",
    Time == "ShaiFUNO_total" ~ "NoWear"
  ))


#######descriptives anaylses

describe(Qualtrics_relevant_order_clean_Rev[, c("pss_total", "pssFUW_total",
"pssFUNO_total", "Shai_total", "ShaiFUW_total", "ShaiFUNO_total" )])

# Descriptives for PSS_total by Time and wearable_dummy
descriptives <- PSS_long %>%
  group_by(Time, wearable_dummy) %>%
  summarise(
    N = sum(!is.na(PSS_total)),
    Mean = mean(PSS_total, na.rm = TRUE),
```

```
    SD = sd(PSS_total, na.rm = TRUE),
    Min = min(PSS_total, na.rm = TRUE),
    Max = max(PSS_total, na.rm = TRUE),
    Variance = var(PSS_total, na.rm = TRUE)
  ) %>%
  ungroup()

print(descriptives)

#no order variable
descriptives_noOrder <- PSS_long %>%
  group_by(Time) %>%
  summarise(
    N = sum(!is.na(PSS_total)),
    Mean = mean(PSS_total, na.rm = TRUE),
    SD = sd(PSS_total, na.rm = TRUE),
    Min = min(PSS_total, na.rm = TRUE),
    Max = max(PSS_total, na.rm = TRUE),
    Variance = var(PSS_total, na.rm = TRUE)
  ) %>%
  ungroup()

print(descriptives_noOrder)

#for shai
descriptives_2 <- SHAI_long %>%
  group_by(Time, wearable_dummy) %>%
  summarise(
    N = sum(!is.na(SHAI_total)),
    Mean = mean(SHAI_total, na.rm = TRUE),
    SD = sd(SHAI_total, na.rm = TRUE),
    Min = min(SHAI_total, na.rm = TRUE),
    Max = max(SHAI_total, na.rm = TRUE),
    Variance = var(SHAI_total, na.rm = TRUE)
```

```
  ) %>%
  ungroup()

print(descriptives_2)

#no order variable
descriptives_2_noOrder <- SHAI_long %>%
  group_by(Time) %>%
  summarise(
    N = sum(!is.na(SHAI_total)),
    Mean = mean(SHAI_total, na.rm = TRUE),
    SD = sd(SHAI_total, na.rm = TRUE),
    Min = min(SHAI_total, na.rm = TRUE),
    Max = max(SHAI_total, na.rm = TRUE),
    Variance = var(SHAI_total, na.rm = TRUE)
  ) %>%
  ungroup()

print(descriptives_2_noOrder)

#variance
var(Qualtrics_relevant_order_clean_Rev$pss_total, na.rm = TRUE)
var(Qualtrics_relevant_order_clean_Rev$pssFUW_total, na.rm = TRUE)
var(Qualtrics_relevant_order_clean_Rev$pssFUNO_total, na.rm = TRUE)
var(Qualtrics_relevant_order_clean_Rev$Shai_total, na.rm = TRUE)
var(Qualtrics_relevant_order_clean_Rev$ShaiFUW_total, na.rm = TRUE)
var(Qualtrics_relevant_order_clean_Rev$ShaiFUNO_total, na.rm = TRUE)


###look at correlation between PSS and SHAI
# Combine PSS and SHAI long data by alias and Time
merged_long <- merge(PSS_long, SHAI_long, by = c("alias", "Time"))

# correlate across all time points
```

```
cor.test(merged_long$PSS_total, merged_long$SHAI_total)

#all time points
merged_long_0 <- merged_long[merged_long$Time == "Baseline", ]
merged_long_W <- merged_long[merged_long$Time == "Wear", ]
merged_long_NW <- merged_long[merged_long$Time == "NoWear", ]

cor_test_0 <- cor.test(merged_long_0$PSS_total, merged_long_0$SHAI_total)
print(cor_test_0)

cor_test_W <- cor.test(merged_long_W$PSS_total, merged_long_W$SHAI_total)
print(cor_test_W)

cor_test_NW <- cor.test(merged_long_NW$PSS_total, merged_long_NW$SHAI_total)
print(cor_test_NW)

#lets make visuals
#PSS
#mean and error for each time point without the dummy variable for order
summary_data_wear <- PSS_long %>%
  group_by(Time) %>%
  summarise(
    mean_PSS = mean(PSS_total, na.rm = TRUE),
    sd_PSS = sd(PSS_total, na.rm = TRUE),
    n = sum(!is.na(PSS_total)),
    se_PSS = sd_PSS / sqrt(n),
    lower_CI = mean_PSS - qt(0.975, df = n - 1) * se_PSS,
    upper_CI = mean_PSS + qt(0.975, df = n - 1) * se_PSS,
    .groups = "drop"
  )

#plot mean trajectory with error bands
p1 <- ggplot(summary_data_wear, aes(x = factor(Time, levels = c("Baseline", "Wear",
"NoWear")),
```

```
                                y = mean_PSS, group = 1)) +
  geom_line(size = 1.2, color = "steelblue") +
  geom_point(size = 3, color = "steelblue") +
  geom_ribbon(aes(ymin = lower_CI, ymax = upper_CI), fill = "steelblue", alpha = 0.4) +
  labs(
    title = "Mean PSS Scores by Wear Condition",
    x = "Condition",
    y = "Mean PSS Score (with 95% CI)"
  ) +
  theme_minimal()

p1

#Do the same for SHAI
summary_data_2 <- SHAI_long %>%
  group_by(Time) %>%
  summarise(
    mean_SHAI = mean(SHAI_total, na.rm = TRUE),
    sd_SHAI = sd(SHAI_total, na.rm = TRUE),
    n = sum(!is.na(SHAI_total)),
    se_SHAI = sd_SHAI / sqrt(n),
    lower_CI = mean_SHAI - qt(0.975, df = n - 1) * se_SHAI,
    upper_CI = mean_SHAI + qt(0.975, df = n - 1) * se_SHAI
  )

#plot mean trajectory with error bands
p2 <- ggplot(summary_data_2, aes(x = factor(Time, levels = c("Baseline", "Wear",
"NoWear")),
                              y = mean_SHAI, group = 1)) +
  geom_line(size = 1.2, color = "steelblue") +
  geom_point(size = 3, color = "steelblue") +
  geom_ribbon(aes(ymin = lower_CI, ymax = upper_CI), fill = "steelblue", alpha = 0.4) +
  labs(
    title = "Mean SHAI Scores by Wear Condition",
```

```
    x = "Condition",
    y = "Mean SHAI Score (with 95% CI)"
  ) +
  theme_minimal()


#make one mean PSS and SHAI plot together
p1+p2




#BOXPLOT
#including jitter function to show all data points on top of the box plot
#this helps to visualise how densely values are packed, whether some groups are more spread
and the it shows the raw distribution

#PSS
PSS_long$Time <- factor(PSS_long$Time, levels = c("Baseline", "NoWear", "Wear"))

pss_box <- ggplot(PSS_long, aes(x = Time, y = PSS_total, fill = Time)) +
  geom_boxplot(position = position_dodge(0.8), width = 0.7, alpha = 0.8, outlier.shape = NA)
+
  geom_jitter(aes(color = Time),
              position = position_jitterdodge(jitter.width = 0.15, dodge.width = 0.8),
              alpha = 0.5, size = 1.5, show.legend = FALSE) +
  scale_fill_manual(values = c("Wear" = "steelblue", "NoWear" = "darkorange")) +
  scale_color_manual(values = c("Wear" = "steelblue", "NoWear" = "darkorange")) +
  scale_y_continuous(limits = c(0, 40), breaks = seq(0, 40, 5)) +
  labs(
    title = "Distribution of PSS Scores",
    x = "Condition",
    y = "PSS Score",
    fill = "Condition"
  ) +
```

```
  theme_minimal()

#same for SHAI
SHAI_long$Time <- factor(SHAI_long$Time, levels = c("Baseline", "NoWear", "Wear"))

shai_box <- ggplot(SHAI_long, aes(x = Time, y = SHAI_total, fill = Time)) +
  geom_boxplot(position = position_dodge(0.8), width = 0.7, alpha = 0.8, outlier.shape = NA)
+
  geom_jitter(aes(color = Time),
              position = position_jitterdodge(jitter.width = 0.15, dodge.width = 0.8),
              alpha = 0.5, size = 1.5, show.legend = FALSE) +
  scale_fill_manual(values = c("Wear" = "steelblue", "NoWear" = "darkorange")) +
  scale_color_manual(values = c("Wear" = "steelblue", "NoWear" = "darkorange")) +
  scale_y_continuous(limits = c(0, 42), breaks = seq(0, 42, 5)) +
  labs(
    title = "Distribution of SHAI Scores",
    x = "Condition",
    y = "SHAI Score",
    fill = "Condition"
  ) +
  theme_minimal()

#combine the jitter box plots
pss_box + shai_box



#density plot
dp1 <- ggplot(PSS_long, aes(x = PSS_total, color = Time, fill = Time)) +
  geom_density(alpha = 0.3) +
  facet_wrap(~ Time, nrow = 1) +
  scale_fill_manual(values = c("Baseline" = "gray70", "Wear" = "steelblue", "NoWear" =
"darkorange"),
                    name = "Condition") +
```

```
  scale_color_manual(values = c("Baseline" = "gray70", "Wear" = "steelblue", "NoWear" =
"darkorange"),
                     guide = "none") +
  labs(
    title = "Density of PSS Scores Across Time Points",
    x = "PSS Score",
    y = "Density"
  ) +
  theme_minimal() +
  theme(legend.position = "bottom")

#same for SHAI
dp2 <- ggplot(SHAI_long, aes(x = SHAI_total, color = Time, fill = Time)) +
  geom_density(alpha = 0.3) +
  facet_wrap(~ Time, nrow = 1) +
  scale_fill_manual(values = c("Baseline" = "gray70", "Wear" = "steelblue", "NoWear" =
"darkorange"),
                    name = "Condition") +
  scale_color_manual(values = c("Baseline" = "gray70", "Wear" = "steelblue", "NoWear" =
"darkorange"),
                     guide = "none") +
  labs(
    title = "Density of SHAI Scores Across Time Points",
    x = "SHAI Score",
    y = "Density"
  ) +
  theme_minimal() +
  theme(legend.position = "bottom")

dp1 + dp2


###Linear Mixed Model####
```

```
##PSS

# Relevel the Time variable so "Wear" is the reference
PSS_long$Time <- relevel(factor(PSS_long$Time), ref = "Wear")

#fit the linear mixed model
lmm_pss <- lmer(PSS_total ~ Time + (1 | alias), data = PSS_long)

# Summary
summary(lmm_pss)

#with order variable#################
lmm_pss_Order <- lmer(PSS_total ~ Time * wearable_dummy + (1 | alias), data = PSS_long)

# Summary
summary(lmm_pss_Order)

#check parametric assumptions

# Extract Residuals
res_pss_time <- residuals(lmm_pss)

#Check normality of residuals
## Q-Q plot
qqnorm(res_pss_time); qqline(res_pss_time)

##Histogram
hist(res_pss_time, breaks = 30, col = "lightblue", main = "Histogram of Residuals", xlab =
"Residuals")

#Check Linearity & Homoscedasticity
##Residuals vs Fitted values
plot(fitted(lmm_pss), res_pss_time,
    xlab = "Fitted values", ylab = "Residuals",
```

```
    main = "Residuals vs Fitted (Homoscedasticity & Linearity)")
abline(h = 0, col = "red", lty = 2)


#same for SHAI ########################
# Relevel the Time variable so "Wear" is the reference
SHAI_long$Time <- relevel(factor(SHAI_long$Time), ref = "Wear")

#fit the linear mixed model
lmm_shai <- lmer(SHAI_total ~ Time + (1 | alias), data = SHAI_long)

# Summary
summary(lmm_shai)

#check model assumptions
# Extract Residuals
res_shai_time <- residuals(lmm_shai)

#Check normality of residuals
## Q-Q plot
qqnorm(res_shai_time); qqline(res_shai_time)

##Histogram
hist(res_shai_time, breaks = 30, col = "lightblue", main = "Histogram of Residuals", xlab =
"Residuals")

#Check Linearity & Homoscedasticity
##Residuals vs Fitted values
plot(fitted(lmm_shai), res_shai_time,
    xlab = "Fitted values", ylab = "Residuals",
    main = "Residuals vs Fitted (Homoscedasticity & Linearity)")
abline(h = 0, col = "red", lty = 2)
```

```
################### m-path
########################################################

#clean data set stress slider
esm_clean <- mPath_relevant %>%
  mutate(
    group = ifelse(`Wearable (1=yes, 0=no)` == 1, "Smartwatch", "Control"),
    group = factor(group),
    stress_score = stressed_sliderNeutralPos
  )


esm_clean_stressed <- esm_clean %>% dplyr::select(alias,`Order (1=wearable in first week, 2=wearable in 2nd week)`
                                                  ,`Wearable (1=yes, 0=no)`:Occasion,stressed_sliderNeutralPos,group,stress_score)
esm_clean_stressed <- na.omit(esm_clean_stressed)



#include compliance rate of the participant
#Summarize compliance per participant
compliance_summary <- esm_clean_stressed %>%
  group_by(alias) %>%
  summarise(
    total_occasions = 48,
    completed_occasions = sum(!is.na(stressed_sliderNeutralPos)),
    compliance_rate = completed_occasions / total_occasions * 100,
    .groups = "drop"
  )
#Extract one row per participant with relevant info
participant_info <- esm_clean_stressed %>%
  dplyr::select("alias":"stress_score") %>%
  distinct()
```

```
#Combine both
esm_compliance <- left_join(compliance_summary, participant_info, by = "alias")

#delete people with a low compliance rate
esm_compliance_filtered <- esm_compliance %>%
  filter(compliance_rate >= 70)

#how many people left?
esm_compliance_filtered %>%
  summarise(participants_remaining = n_distinct(alias))



#### more #####
#esm long format
weekly_stress <- esm_compliance_filtered %>%
  group_by(alias, Week) %>%
  summarise(
    average_momentary_stress = mean(stressed_sliderNeutralPos, na.rm = TRUE),
    `Order (1=wearable in first week, 2=wearable in 2nd week)` = first(`Order (1=wearable in first week, 2=wearable in 2nd week)`),
    `Wearable (1=yes, 0=no)` = first(`Wearable (1=yes, 0=no)`)
  )%>%
  ungroup()

#add wearable column (as wearable yes no is NA)
weekly_stress <- esm_compliance_filtered %>%
  group_by(alias, Week) %>%  # group by participant and week
  summarise(
    average_momentary_stress = mean(stressed_sliderNeutralPos, na.rm = TRUE),  # compute average stress
    `Order (1=wearable in first week, 2=wearable in 2nd week)` = first(`Order (1=wearable in first week, 2=wearable in 2nd week)`),  # preserve order group
    `Wearable (1=yes, 0=no)` = first(`Wearable (1=yes, 0=no)`)  # preserve wearable condition
  ) %>%
```

```
  ungroup()

#Visualising it
#box plot
#with the jitter things
weekly_stress$`Wearable (1=yes, 0=no)` <- factor(weekly_stress$`Wearable (1=yes, 0=no)`,
levels = c(0, 1), labels = c("No Wear", "Wear"))

#the wearable yes no variable had NA
weekly_stress$`Wearable (1=yes, 0=no)` <- ifelse(
  (weekly_stress$Week == 1 & weekly_stress$`Order (1=wearable in first week, 2=wearable
in 2nd week)` == 1) |
    (weekly_stress$Week == 2 & weekly_stress$`Order (1=wearable in first week, 2=wearable
in 2nd week)` == 2),
  1,  # this week is the wearable week
  0   # this week is the no-wearable week
)

esm_p1 <- ggplot(weekly_stress, aes(x = factor(`Wearable (1=yes, 0=no)`), y =
average_momentary_stress)) +
  geom_boxplot(aes(fill = factor(`Wearable (1=yes, 0=no)`)),
               alpha = 0.7, width = 0.6, outlier.shape = NA) +
  geom_jitter(aes(color = factor(`Wearable (1=yes, 0=no)`)),
              position = position_jitter(width = 0.15, height = 0),
              alpha = 0.5, size = 1.5, show.legend = FALSE) +
  scale_fill_manual(values = c("0" = "darkorange", "1" = "steelblue"),
                    labels = c("0" = "No Wear", "1" = "Wear"),
                    name = "Condition") +
  scale_color_manual(values = c("0" = "darkorange", "1" = "steelblue")) +
  scale_x_discrete(labels = c("0" = "No Wear", "1" = "Wear")) +
  labs(
    title = "Average Momentary Stress",
    x = "Wearable Condition",
    y = "Average Momentary Stress"
```

```
  ) +
  theme_minimal() +
  theme(
    plot.title = element_text(size = 14),
    axis.title = element_text(size = 12),
    axis.text = element_text(size = 10),
    legend.position = "none"
  )

esm_p1

#line plot (mean stress trajectory over weeks)
# Summarise by Week and Wearable condition
weekly_summary <- weekly_stress %>%
  group_by(Week, `Wearable (1=yes, 0=no)`) %>%
  summarise(
    mean_stress = mean(average_momentary_stress, na.rm = TRUE),
    sd_stress = sd(average_momentary_stress, na.rm = TRUE),
    n = n(),
    .groups = "drop"
  ) %>%
  mutate(se_stress = sd_stress / sqrt(n))

# Set factor levels for labeling
weekly_summary$`Wearable (1=yes, 0=no)` <- factor(
  weekly_summary$`Wearable (1=yes, 0=no)`,
  levels = c(0, 1),
  labels = c("No Wear", "Wear")
)

# Plot
esm_p2 <- ggplot(weekly_summary, aes(x = Week, y = mean_stress,
                                   color = `Wearable (1=yes, 0=no)`,
                                   group = `Wearable (1=yes, 0=no)`)) +
```

```
  geom_line(size = 1.2) +
  geom_point(size = 3) +
  geom_errorbar(aes(ymin = mean_stress - se_stress, ymax = mean_stress + se_stress),
                width = 0.2) +
  scale_color_manual(values = c("No Wear" = "darkorange", "Wear" = "steelblue")) +
  scale_x_continuous(breaks = c(1, 2)) +
  labs(
    title = "Mean Weekly Stress Scores",
    x = "Week",
    y = "Mean Average Momentary Stress",
    color = "Condition"
  ) +
  theme_minimal() +
  theme(
    plot.title = element_text(size = 14),
    axis.title = element_text(size = 12),
    axis.text = element_text(size = 10),
    legend.position = "right"
  )

esm_p2
esm_p1 + esm_p2

#####linear mixed model##############################
#esm linear model
# Fit the model
esm_lmm <- lmer(
  average_momentary_stress ~ `Wearable (1=yes, 0=no)` + (1 | alias),
  data = esm_long
)

summary(esm_lmm)

# Fit the model
```

```
#this is also about week (does not matter?)
esm_lmm <- lmer(
  average_momentary_stress ~ Week * `Wearable (1=yes, 0=no)` + (1 | alias),
  data = esm_long
)
#this is random intercept and random slope
#if I do random intercept and random slope (as there are many measuerments a day)
esm_lmm <- lmer(
  average_momentary_stress ~ Week + (Week | alias),
  data = esm_long_again
)

summary(esm_lmm)



#the assumptions testing

# Extract Residuals
res_esm <- residuals(esm_lmm)

#Check normality of residuals
## Q-Q plot
qqnorm(res_esm); qqline(res_esm)

##Histogram
hist(res_esm, breaks = 30, col = "lightblue", main = "Histogram of Residuals", xlab =
"Residuals")

#Check Linearity & Homoscedasticity
##Residuals vs Fitted values
plot(fitted(esm_lmm), res_esm,
     xlab = "Fitted values", ylab = "Residuals",
     main = "Residuals vs Fitted (Homoscedasticity & Linearity)")
```

```
abline(h = 0, col = "red", lty = 2)




#### compare Qualtrics and ESM ###
#PSS_long into wide format
PSS_wide <- PSS_long %>%
  pivot_wider(
    id_cols = c(alias,wearable_dummy),         # participant alias and wearable dummy column, 
as they are connected
    names_from = Time,                         # the column with time points (e.g., Baseline, Wear, 
NoWear)
    values_from = PSS_total                    # the column with the scores
  )

#make ESM data wide
esm_wide <- weekly_stress %>%
  dplyr::select(alias, Week, average_momentary_stress, `Wearable (1=yes, 0=no)`) %>%
  pivot_wider(
    names_from = Week,
    values_from = c(average_momentary_stress, `Wearable (1=yes, 0=no)`),
    names_sep = "_Week_"
  )

#pivot back to long format to add week variable
esm_long_again <- esm_wide %>%
  pivot_longer(
    cols = starts_with("Week_"),
    names_to = "Week",
    names_prefix = "Week_",
    values_to = "average_momentary_stress"
  )
```

```
esm_long <- esm_wide %>%
  pivot_longer(
    cols = c(starts_with("average_momentary_stress_Week_"), starts_with("Wearable (1=yes, 
0=no)_Week_")),
    names_to = c(".value", "Week"),
    names_pattern = "(.*)_Week_(\\d)"
  ) %>%
  mutate(Week = as.numeric(Week))

#add vaiable wearable_dummy to esm_wide
esm_wide <- esm_long %>%
  mutate(
    wearable_dummy = case_when(
      (`Order (1=wearable in first week, 2=wearable in 2nd week)` == 1 & Week == 1) ~ 0,
      (`Order (1=wearable in first week, 2=wearable in 2nd week)` == 1 & Week == 2) ~ 1,
      (`Order (1=wearable in first week, 2=wearable in 2nd week)` == 2 & Week == 1) ~ 1,
      (`Order (1=wearable in first week, 2=wearable in 2nd week)` == 2 & Week == 2) ~ 0,
      TRUE ~ NA_real_
    )
  )

colnames(esm_long)



esm_long <- esm_long %>%
  left_join('Wearable (1=yes, 0=no)', by = "alias")



#combine the data
combined_data <- left_join(
  PSS_wide,    # Your Qualtrics wide dataset
  esm_wide,         # Your ESM wide dataset
  by = c("alias")
```

```
)


#compare average momentary stress and wear and account for dummy variable
combined_data_wear_stress <- esm_wide %>%
  mutate(
    stress_wear = ifelse(wearable_dummy == 0, average_momentary_stress_1,
average_momentary_stress_2)
  )

#make 1 and 2 momentary stress
esm_wide_clean_wide <- esm_wide_clean %>%
  dplyr::select(alias, average_momentary_stress, wearable_dummy) %>%
  pivot_wider(
    names_from = Week,
    values_from = c(average_momentary_stress, wearable_dummy),
    names_sep = "_Week_"
  )

##visualisation
ggplot(combined_data, aes(x = Wear, y = Week_2)) +
  geom_point(aes(color = factor(wearable_dummy.x))) +
  geom_smooth(method = "lm", se = FALSE, color = "black") +
  labs(
    title = "Relationship Between PSS (Wear) and ESM Stress (Week 2)",
    x = "PSS Score (Wear Week)",
    y = "Average Momentary Stress (Week 2)",
    color = "Wearable Order\n(0 = Wearable Week 1, 1 = Week 2)"
  ) +
  theme_minimal()


#####discriptives for ESM######
```

```
describe(Qualtrics_relevant_order_clean_Rev[, c("pss_total", "pssFUW_total",
"pssFUNO_total", "Shai_total", "ShaiFUW_total", "ShaiFUNO_total" )])

# Descriptives for esm_compliance_filtered by Time and wearable_dummy
descriptives <- esm_compliance_filtered %>%
  group_by( group, `Wearable (1=yes, 0=no)`) %>%
  summarise(
    N = sum(!is.na(stressed_sliderNeutralPos)),
    Mean = mean(stressed_sliderNeutralPos, na.rm = TRUE),
    SD = sd(stressed_sliderNeutralPos, na.rm = TRUE),
    Min = min(stressed_sliderNeutralPos, na.rm = TRUE),
    Max = max(stressed_sliderNeutralPos, na.rm = TRUE),
    Variance = var(stressed_sliderNeutralPos, na.rm = TRUE)
  ) %>%
  ungroup()

print(descriptives)

esm_group_descriptives <- weekly_stress %>%
  group_by(`Wearable (1=yes, 0=no)`) %>%
  summarise(
    n = sum(!is.na(average_momentary_stress)),
    mean = mean(average_momentary_stress, na.rm = TRUE),
    sd = sd(average_momentary_stress, na.rm = TRUE),
    min = min(average_momentary_stress, na.rm = TRUE),
    max = max(average_momentary_stress, na.rm = TRUE)
  )

print(esm_group_descriptives)

#esm linear model
# Fit the model
esm_lmm <- lmer(
  average_momentary_stress ~ Week + (1 | alias),
```

```
  data = esm_long_again
)

summary(esm_lmm)


#the assumptions testing


# Extract Residuals
res_esm <- residuals(esm_lmm)

#Check normality of residuals
## Q-Q plot
qqnorm(res_esm); qqline(res_esm)

##Histogram
hist(res_esm, breaks = 30, col = "lightblue", main = "Histogram of Residuals", xlab =
"Residuals")

#Check Linearity & Homoscedasticity
##Residuals vs Fitted values
plot(fitted(esm_lmm), res_esm,
     xlab = "Fitted values", ylab = "Residuals",
     main = "Residuals vs Fitted (Homoscedasticity & Linearity)")
abline(h = 0, col = "red", lty = 2)




####to combine PSS and ESM
# Assume you have wearable order info
pss_weekly <- PSS_long %>%
  mutate(
```

```
    Week = case_when(
      Time == "Baseline" ~ "Baseline",
      Time == "Wear" & wearable_dummy == 0 ~ "Week 1",  # Wear first
      Time == "Wear" & wearable_dummy == 1 ~ "Week 2",  # Wear second
      Time == "NoWear" & wearable_dummy == 0 ~ "Week 2",
      Time == "NoWear" & wearable_dummy == 1 ~ "Week 1"
    )
  ) %>%
  filter(Week %in% c("Week 1", "Week 2")) %>%
  group_by(alias, Week) %>%
  summarise(pss_stress = mean(PSS_total, na.rm = TRUE))

#have to add something in PSS long
PSS_long_ESM <- PSS_long %>%
  mutate(Week = case_when(
    Time == "Baseline" ~ 0,
    Time == "Wear" ~ 1,
    Time == "NoWear" ~ 2
  ))

pss_weekly <- PSS_long_ESM %>%
  group_by(alias, Week) %>%
  summarise(pss_total = mean(PSS_total, na.rm = TRUE))
#join them
weekly_stress$Week <- as.numeric(weekly_stress$Week)  # ensure same type
combined_stress <- left_join(weekly_stress, pss_weekly, by = c("alias", "Week"))

#compare them
cor.test(combined_stress$average_momentary_stress, combined_stress$pss_total)

#lmm including both
#make method variable
combined_stress_wide <- combined_stress %>%
  pivot_longer(
```

```
    cols = c(average_momentary_stress, pss_total),
    names_to = "Method",
    values_to = "Stress"
  )

combined_stress_wide <- combined_stress %>%
  pivot_wider(
    cols = c(average_momentary_stress, pss_total),
    names_to = "Method",
    values_to = "Stress"
  )

combined_long <- combined_wide %>%
  pivot_longer(
    cols = c(average_momentary_stress, pss_total),
    names_to = "Method",
    values_to = "Stress"
  ) %>%
  mutate(
    Method = case_when(
      Method == "average_momentary_stress" ~ "ESM",
      Method == "pss_total" ~ "PSS"
    )
  )

PssEsm_lmm <- lmer(Stress ~ `Wearable (1=yes, 0=no)` * Method + (1 | alias), data =
combined_stress_long )

summary(PssEsm_lmm)

#different again (picked it)
combined_stress_long$`Wearable (1=yes, 0=no)` <-
relevel(factor(combined_stress_long$`Wearable (1=yes, 0=no)`), ref = "1")
```

```
combined_stress_long$Method <- relevel(factor(combined_stress_long$Method), ref =
"pss_total")

PssEsm_lmm_1 <- lmer(Stress ~ `Wearable (1=yes, 0=no)` * Method + (1 | alias), data =
combined_stress_long )

summary(PssEsm_lmm_1)

#parametric assumptions
#the assumptions testing



# Extract Residuals
res_PssEsm_lmm_1 <- residuals(PssEsm_lmm_1)

#Check normality of residuals
## Q-Q plot
qqnorm(res_PssEsm_lmm_1); qqline(res_PssEsm_lmm_1)

##Histogram
hist(res_PssEsm_lmm_1, breaks = 30, col = "lightblue", main = "Histogram of Residuals",
xlab = "Residuals")

#Check Linearity & Homoscedasticity
##Residuals vs Fitted values
plot(fitted(PssEsm_lmm_1), res_PssEsm_lmm_1,
    xlab = "Fitted values", ylab = "Residuals",
    main = "Residuals vs Fitted (Homoscedasticity & Linearity)")
abline(h = 0, col = "red", lty = 2)
```