Exploring Physiological and Psychological Stress Responses in Lean and Non-Lean Individuals Using Ambulatory Monitoring and the VR Trier Social Stress Test

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Abstract

Background: Stress affects both mental and physical health and triggers psychological and physiological responses. Electrodermal activity (EDA) measures physiological stress through sweat gland activity. Stress is also closely linked to obesity and influences each other. However, research on stress responses across body composition in real-world and laboratory settings is limited. Advances in wearable devices and virtual reality now allow for continuous stress monitoring and controlled stress simulations, offering new opportunities to explore how stress perception and physiological responses vary across contexts and body weight groups.

Methods: This study employed a mixed design to examine stress responses in lean and non-lean individuals across daily life and a controlled laboratory setting. The Virtual Reality Trier Social Stress Test (VR TSST) was utilised to induce stress in the laboratory and participants wore EmbracePlus wearable devices to measure EDA both during daily life and the VR-TSST continuously. To capture self-reported perceived stress and coping strategies, participants completed ecological momentary assessments (EMA) at multiple time points throughout the day.

Results: Participants (n=32) reported slightly higher stress in daily life, though this difference was not statistically significant. However, EDA variability was significantly greater in daily life, highlighting the complexity of real-world stress. Non-lean individuals (n=15) exhibited higher EDA levels, though this difference was not statistically significant, and 4 reported engaged in stress eating.

Discussion: Stress levels and EDA variability were higher in daily life which indicates predictable and unpredictable stressors can disrupt daily routines and gradually contribute to overall stress levels. Non-lean individuals showed higher mean EDA in both conditions, which may be influenced by additional factors, such as individual differences in stress perception, environmental conditions, physical activity, and body temperatures. The use of EMA and wearable devices provided valuable insights into stress responses. However, a small, homogenous sample limits generalizability. Future research should include more diverse populations and precise body composition metrics.

Keywords: Stress, Electrodermal Activity, Empatica EmbracePlus, Wearable, Virtual Reality, Perceived Stress Level, Lean, Non Lean, Ambulatory Monitoring, Ecological Momentary Assessment

Introduction

Stress is a complex response to external challenges that individuals encounter throughout their lives which significantly impacts various aspects of both physical and mental health (Park et al., 2023; van Lier et al., 2019). These stressors can trigger a variety of psychological and physiological responses, which vary from person to person (Baghurst & Kelley, 2013; Seaward, 2018). One way to measure physiological stress response is through electrodermal activity (EDA) which reflects a sweat gland activity controlled by the sympathetic nervous system (Rahma et al., 2022; Yu et al., 2024)

Beyond its impact on mental and physical health, stress is also closely linked to obesity, a growing global health concern characterized by excessive body fat accumulation resulting from prolonged unhealthy lifestyles and poor eating habits (World Health Organization [WHO], 2024). Research suggests that stress and obesity are interconnected through both behavioural and physiological pathways. Stress can trigger unhealthy coping mechanisms, such as overeating and reduced physical activity, which contribute to weight gain (Park et al., 2023). Furthermore, obesity is associated with increased stress sensitivity, potentially intensifying the cycle of stress and obesity (Kumar et al., 2022).

To better understand how stress responses vary across contexts and weight status, recent advances in technology, including wearable devices and virtual reality (VR), provide innovative ways to monitor, treat, and evaluate health conditions. This offers new possibilities for real-time health tracking and personalized care in both daily life and laboratory settings (Guk et al., 2019; Hanshans et al., 2024; Kouijzer et al., 2023). Wearable devices enable continuous monitoring of stress biomarkers including heart rate, electrodermal activity, and other related metrics, which offers valuable insights into an individual’s real-time stress levels (González Ramírez et al., 2023; Jerath et al., 2023). Similarly, VR has emerged as a powerful tool for simulating stress-inducing scenarios, allowing researchers to assess physiological and psychological stress responses in a controlled environment (Dammen et al., 2022; Hanshans et al., 2024).

Despite growing interest in the relationship between stress and weight status, many studies typically focus on daily life settings (Kühnel et al., 2023; Scott et al., 2012; van der Valk et al., 2018). Only a few studies have directly compared stress responses across different contexts, specifically both daily life and laboratory-controlled settings (Kidd et al., 2014). Furthermore, while Aldosky (2019) investigated the impact of gender and obesity differences on electrodermal activity (EDA), that study was conducted exclusively in daily life contexts and did not incorporate ambulatory monitoring alongside controlled laboratory stress testing. This limited scope restricts our understanding of how stress perception and physiological responses (especially EDA) shift between real-world experiences and structured laboratory challenges. This leaves an important gap in understanding stress responsivity across different contexts and individual differences particularly when objective physiological monitoring is combined with self-reported stress levels. Examining stress responses in both real-world and laboratory-controlled settings provides complementary insights, as daily life assessments capture naturally occurring stressors and coping mechanisms, while laboratory studies allow for controlled manipulation of stress and precise physiological measurement. Integrating these perspectives is important for a more comprehensive understanding of stress responsivity across different contexts and individual differences, particularly when combining objective physiological monitoring with self-reported stress levels.

This study, therefore, aims to explore how perceived stress levels, coping strategies, and physiological stress responses, particularly electrodermal activity (EDA), differ between lean and non-lean individuals across both daily life and controlled laboratory settings. By addressing this gap, this study will contribute to a clearer understanding of how weight status influences stress responses and coping across different contexts. Understanding these patterns is essential for developing personalized stress management strategies, particularly for populations at higher risk of stress-related health complications, such as individuals with obesity.

Stress

Stress has two distinct meanings: stressors (or stress exposure) and stress response. Stressors refer to environmental challenges or events individuals face, which can differ in duration (acute or chronic), and severity (ranging from minor to traumatic), and occur across the lifespan (Harkness & Hayden, 2020). In contrast, the stress response describes an individual's internal reaction to these stressors, which can be measured at various levels, including psychological states and physiological processes, and may occur before, during, or after the exposure to the stressors (Crosswell & Lockwood, 2020; Harkness & Hayden, 2020).

Acute stress arises from a specific triggering event and can be categorised as active or passive. Active stressors demand a direct response from the individual. In a laboratory setting, this might involve giving an impromptu speech or solving mental arithmetic problems, while in daily life, this includes job interviews. Passive stressors, on the other hand, do not require any active response. This could involve watching disturbing films in the laboratory setting, whereas, in real life, it might include waiting for test results (Epel et al., 2018). The responses to acute stressors involve conscious processes, such as evaluating the situation, and unconscious processes that influence the brain and body without awareness.

Chronic stressors are long-term stressors that can affect an individual's physical health, mental well-being, relationships, and community dynamics (Epel et al., 2018; Romas & Sharma, 2022). This can include financial difficulties, interpersonal stressors (e.g., loneliness, social isolation, relationship conflicts, and discrimination), and work-related stress. Chronic stress can have profound health impacts. For instance, interpersonal stress and financial strain may lead to depressive symptoms (Slavich et al., 2020), while work stress and burnout are associated with high blood pressure and cardiovascular diseases (John et al., 2024).

Stress occurs when an individual perceives environmental demands as exceeding their ability to cope or manage them (Lazarus et al., 1985). This perception, known as perceived stress, is a subjective evaluation that can be influenced by factors like life experiences, health status, and social support (Park et al., 2023) and involves various psychological aspects of the stress response (Epel et al., 2018). High perceived stress levels can lead to reduced physical activity, unhealthy habits like poor diet and smoking, and various health problems, including weakened immunity, cardiovascular issues, diabetes, and mental health disorders such as depression and anxiety (Park et al., 2023).

Stress responses are different between people and these can be measured in various ways such as using self-report questionnaires, interviews, and physiological measurements (Crosswell & Lockwood, 2020). These stress responses include psychological (e.g. anxiety), physiological (e.g. changes in heart rate and skin conductivity), cognitive (e.g. reduced ability to pay attention and poorer cognitive function), and behavioural responses (smoking, undereating, and overeating) (Chu et al., 2025; Scott et al., 2012). The physiological stress responses can be assessed using biomarkers (e.g. wearables) while the most common way to evaluate the other stress responses is via a self-report questionnaire (Crosswell & Lockwood, 2020). Given the profound impact of stress on both psychological and physiological health, it is important to consider its role in conditions such as obesity, which is influenced by both behavioural and biological stress-related mechanisms.

Obesity

The World Health Organization (WHO) (n.d.) defines overweight and obesity as the accumulation of excess fat in the body, which can pose a health risk. A person is classified as overweight when their body mass index (BMI) falls between 25.0 and 29.9, and obese when their BMI is 30.0 or higher (WHO, 2024). In 2022, one out of eight people was affected by obesity (WHO, 2024). Additionally, 35% of people aged 20 and over in the Netherlands were classified as having moderate overweight, with a BMI ranging from 25 to 30 (RIVM, 2024).

The causes of obesity vary, ranging from non-modifiable to modifiable factors. Certain types of genetics, such as monogenic, polygenic, and syndromic, are non-modifiable factors contributing to obesity (Masood & Moorthy, 2023; Tirthani et al., 2023). In contrast, modifiable factors encompass behaviours such as excessive calorie intake which exceeds energy expenditure and being physically inactive and sedentary behaviour which decreases energy expenditure (Romieu et al., 2017). Moreover, psychosocial stress might lead to emotional/comfort eating which results in weight gain over time (Masood & Moorthy, 2023). Lastly, insufficient sleep is associated with an increase in BMI and a higher risk of obesity due to increased hunger and appetite, craving for calorie-dense foods and increased fatigue which may lower the capability for exercise (Cooper et al., 2018).

Obesity has a significant negative impact on health-related quality of life and is associated with a range of diseases. On average, obese individuals have a shorter lifespan of about two years compared to those with normal weight (Djalalinia et al., 2015). It is also one of the main causes of cardiovascular diseases such as heart failure, coronary heart disease and stroke. Obesity is a modifiable risk factor that significantly contributes to the onset and progression of type 2 diabetes mellitus by diminishing insulin sensitivity, which is caused by a reduction in functional β-cell mass (Lam et al., 2023; Ruze et al., 2023). Additionally, obesity is a risk factor for dementia and is associated with several types of cancer, including breast and stomach cancer (Pati et al., 2023).

Psychologically, individuals with obesity are more likely to experience depression and anxiety than those with normal weight (Steptoe & Frank, 2023). They often face psychological challenges such as stress associated with weight-related issues, perceived weight discrimination and stigmatisation. Women, in particular, often feel dissatisfied with their body image due to social pressures which can lead to decreased self-esteem and self-efficacy (Lam et al., 2023).

Stress and Obesity

Stress and obesity are closely intertwined through cognitive, behavioural, and physiological pathways (Kumar et al., 2022; van der Valk et al., 2018). When exposed to stress, the body releases a hormone called glucocorticoid which plays an important role in mediating stress response (Srinivasan et al., 2013). One example of glucocorticoid is cortisol during stressful events which allows the body to stay alert (James et al., 2023). However, chronic excess of glucocorticoids can disrupt the regulation of hormones responsible for regulating appetite and maintaining energy balance and emotional well-being. This disruption can heighten the desire to eat for pleasure (particularly highly palatable foods) and lead to mood imbalances, reducing the body's ability to control hunger. As a result, this may lead to hedonic overeating (Kuckuck et al., 2023). Additionally, stress can impair cognitive function such as self-regulation, which hinders healthy decision-making. Behaviorally, stress may lead to overeating, particularly of calorie-dense, fatty, and sugary foods (Kumar et al., 2022).

Chronic social stressors, such as financial strain, interpersonal conflicts, work-related stress, lack of social support, and low self-esteem, can contribute to obesity by affecting appetite and food choices (Scott et al., 2012). This effect is particularly pronounced in individuals with obesity, who experience other stressors such as weight stigma and discrimination (van der Valk et al., 2018; Verdejo-Garcia et al., 2019). Additionally, they are more likely to suffer from mental health issues (e.g., depression) and physical disorders (e.g., sleep apnea, chronic pain), which can contribute to chronic stress and elevated cortisol levels (van der Valk et al., 2018).

Obesity itself is associated with elevated cortisol levels, which contribute to chronic stress, poor dietary habits, and sleep disruption (Kumar et al., 2022). These individuals tend to be more sensitive to stress, showing a stronger cortisol response to the same stressors compared to individuals of healthy weight and also exhibit cognitive control deficits (Verdejo-Garcia et al., 2019). They are more likely to experience intense cravings and heightened sensitivity to rewarding foods in response to stress- a reaction not typically seen in those of healthy weight. For some, overeating becomes similar to an addiction to these foods (Verdejo-Garcia et al., 2019).

Moreover, acute stressors tend to trigger a stronger stress response and have a more negative impact on cognition in overweight and obese individuals compared to those with a healthy weight (Verdejo-Garcia et al., 2019). The effect of stress on obesity may also differ based on factors like sex, age, stress perception, coping strategies, and control over stressful situations (Park et al., 2023). For example, in adult males, obesity was significantly linked to perceived stress levels, while in adult females, perceived stress did not have a notable impact on obesity or hypertension rates (Park et al., 2023).

Electrodermal Activity

When an individual encounters a perceived threat or challenge, the sympathetic nervous system (SNS) is quickly activated, triggering the "fight or flight" response. This activation increases sweat gland activity and stimulates greater secretion from the sweat ducts, which in turn causes changes in the skin's electrical conductance, a phenomenon known as electrodermal activity (EDA) (Pop-Jordanova & Pop-Jordanov, 2020; Yu et al., 2024). A common parameter used to measure EDA is skin conductance response (SCR), which represents brief, phasic responses triggered by specific external stimuli.

Research by Klimek et al. (2023) found a positive correlation between EDA and perceived stress, showing that emotional arousal shifts in response to environmental stimuli. Both positive emotions, such as joy, and negative emotions, such as fear or threat, lead to increased eccrine sweat gland activity. As emotional arousal rises, skin conductance also increases, with stronger stimuli causing a greater increase in conductance. Thus, EDA serves as an indicator of emotional or cognitive responses related to stress or mental health (Rahma et al., 2022), reflecting the intensity of the emotional reaction rather than the specific emotion itself (Pop-Jordanova & Pop-Jordanov, 2020).

Various factors, such as individuals’ characteristics and environmental conditions, can influence EDA. For instance, obesity may alter skin physiology, while gender differences can lead to variations in sweat gland activation (Aldosky, 2019). Furthermore, it was found that males exhibit unexpectedly greater sensitivity to stimuli in their skin conductance responses (SCRs) compared to females (Aldosky, 2019).

EDA is typically measured in microsiemens and can be recorded from various body parts, including the fingertips, middle and proximal phalanges of the fingers, several palmar areas, the wrist, and one dorsal point on the forearm (Boucsein, 2012). The medial phalanges of the index and middle fingers are considered the most reliable sites for recording EDA due to their reduced susceptibility to movement and scarring (Klimek et al., 2023). Additionally, the non-dominant hand is generally preferred for recording because it is less likely to be calloused, experiences fewer movement artefacts, and allows the dominant hand to remain free for other tasks such as writing (Boucsein, 2012).

Wearables

The classical approach to electrodermal activity (EDA) measurement typically involves placing the electrode on the finger and the palm (Boucsein et al., 2012). However, this method can be restrictive and impractical for continuous monitoring in daily life as it can interfere with daily activities (van der Mee et al., 2021). To overcome this limitation, wearable technology has emerged as a promising alternative, enabling real-time, noninvasive EDA tracking beyond laboratory settings (Canali et al., 2022; Klimek et al., 2023). Wearable technology, also known as wearable devices or wearables refers to devices worn on our body parts (such as the wrist, hand, or neck). Wearables are noninvasive, real-time biosensors, commonly used in daily life and clinical settings for continuous monitoring of health metrics and tracking exercise activity (Jerath et al., 2023). Examples of widely utilised wearable technologies include headbands, sociometric badges, cameras, smartwatches, and textile sensors (Vijayan et al., 2021).

These devices are equipped with sensors that continuously monitor physiological signals, including heart rate, temperature, and galvanic skin response (González Ramírez et al., 2023). They offer real-time feedback, help assess health status, and assist with preliminary medical diagnoses, for instance, when the stress level or the heart rate is too high (Guk et al., 2019). The provided real-time feedback also enables users to modify their lifestyle to maintain better health status. This use of wearables reflects a broader shift from hospital-centred care to home-based personal health management, with the aim of cutting healthcare expenses (Bandodkar & Wang, 2014). Wu et al. (2023) showed that wearable activity trackers are an effective tool for increasing physical activity in older adults while also helping to reduce sedentary behaviour.

One example is the Empatica Embraceplus wristband, which is a wearable device that collects real-time physiological data using four sensors: a photoplethysmograph (PPG), an electrodermal activity sensor, a three-axis accelerometer, and a temperature sensor (Milstein & Gordon, 2020; van Lier et al., 2019). This wearable monitors EDA using two dry electrodes on the back of the watch which allows continuous and noninvasive tracking. While wearables provide valuable insights into physiological responses, they are primarily used for monitoring rather than inducing stress. Therefore, controlled stress induction is sometimes used to systematically study stress responses in experimental settings.

Virtual Reality Trier Social Stress Test

The advancements in virtual reality have provided an innovative approach to assessing stress responses. Among these, the Trier Social Stress Test (TSST) has become one of the most widely used methods to induce acute psychosocial stress in experimental settings (Allen et al., 2014; Labuschagne et al., 2019). The Trier Social Stress Test (TSST), developed by Kirschbaum et al. (1993), is a highly reliable, valid, and standardized way to induce psychosocial stress in laboratory settings. The test is divided into three phases, each lasting 5 minutes, which include a preparation task, a speech task, and an arithmetic task.

The mock job interview and arithmetic tasks are performed in front of three panel members who offer no emotional reactions or social feedback and maintain neutral facial expressions. The ambiguity of a neutral expression could contribute to a higher cortisol stress response in the participants (Labuschagne, 2019). The test begins with a five-minute preparation phase where participants are asked to prepare a speech explaining their strengths and weaknesses to apply for a dream job. In the subsequent speech task, participants need to speak for the entire five minutes and the panel members will encourage them to say more by saying “You still have time remaining” or “Okay that’s enough, now proceed with the weaknesses”. The final task is an arithmetic task in which participants need to subtract the number 7 from 1022 as fast and accurately as possible. In case of error, they will have to start again and the panel members will say “Incorrect. Start over” or “Too slow. Start over”.

Due to several limitations while conducting the in vivo (laboratory setting) TSST, researchers have developed a virtual reality version (VR-TSST), which can generate similar stress responses (Fallon et al., 2021). The VR-TSST is a practical, standardized tool for eliciting physiological responses (such as heart rate and blood pressure) and psychological responses (perceived stress and anxiety) similar to the traditional in vivo TSST (Fallon et al., 2021; Shiban et al., 2016). This suggested that VR-TSST is a reliable alternative for stress induction in controlled settings.

Objectives

Previous studies have examined the association between obesity and stress, yet few have examined physiological stress responses using both ambulatory monitoring and controlled stress induction to assess physiological stress responses. Moreover, how weight status influences perceived stress and physiological markers like EDA across different contexts remains limited. To address this gap, this study investigates stress responses (electrodermal activity, perceived stress level, and coping strategies) across two settings: daily life and controlled laboratory conditions. Given that weight status may influence stress stress responses, this study examines differences:

1. Within subjects: Examining the stress responses of the same individuals between daily life and laboratory condition.
2. Between subjects: Investigating how lean vs. non-lean individuals differ in their stress responses across both environments in both daily life and controlled laboratory conditions.

To answer the first objective (contextual differences in stress responses), the following research questions (RQ) are made:

RQ 1: Do individuals within this sample experience higher stress levels in daily life or a controlled laboratory setting?

RQ 2: Do individuals within this sample exhibit greater electrodermal activity (EDA) variability in daily life compared to a controlled laboratory condition?

To address the second objective (weight-related differences in stress responses), the following RQ are made:

RQ 3: How do lean and non-lean individuals within this sample differ in their coping strategies after experiencing a stressful laboratory condition?

RQ 4: Is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals during daily life conditions within this sample?

RQ 5: Is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals under lab-controlled conditions within this sample?

RQ 6: Do lean individuals exhibit higher EDA reactivity than non-lean individuals during each stress task?

Method

Study Design

The study employed a within-subject and between-subject design and was conducted under two conditions: daily life and a laboratory setting. The study lasted for two days (see Figure 1). Before the start of the experiment, participants came to the laboratory to get their Embrace Plus and enrolled in the study on the Twente Intervention and Interactive Machine (TIIM) App. They were provided with informed consent, a QR code to connect the EmbracePlus device to the Care App and a voucher code to register for the study on the TIIM App.

On the first day, participants completed a set of questionnaires on the TIIM App and wore the EmbracePlus device throughout the day to monitor electrodermal activity (EDA). On the second day, participants returned to the laboratory to undergo the Virtual Reality Trier Social Stress Test (VR TSST). The VR experiment consisted of five sessions, as outlined in Figure 2: a baseline measurement, three phases of VR task, and a recovery phase.

Figure 1

Study Procedure Overview

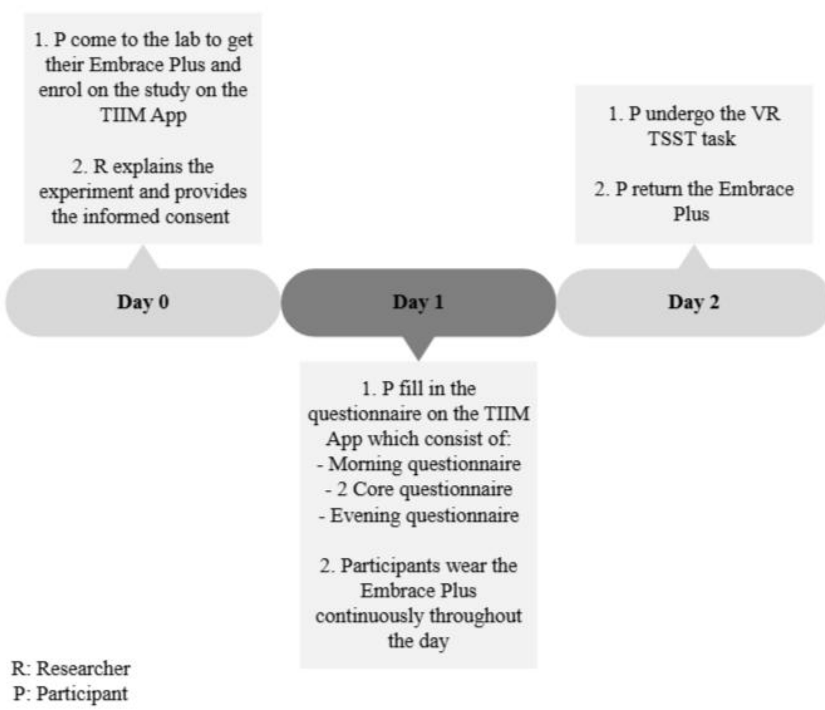
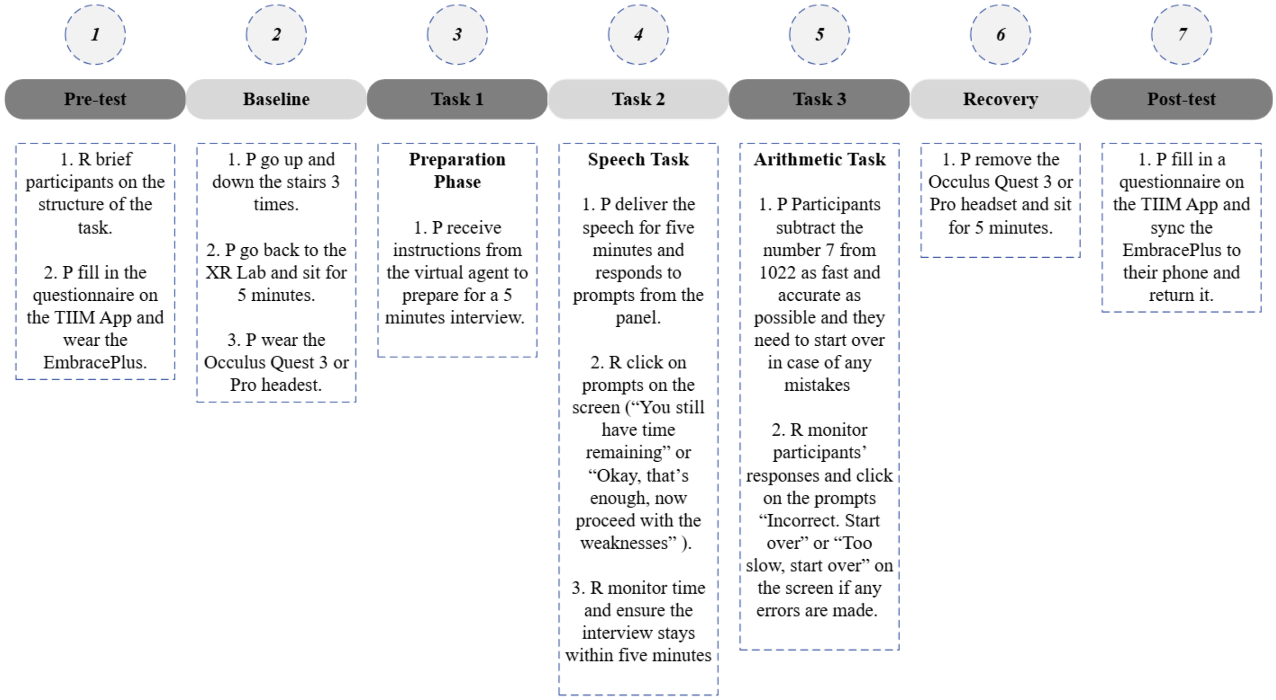


Figure 2

Phases of the Virtual Reality Trier Social Stress Test (VR TSST)



Participants

Data collection took place from January 13, 2025, to February 18, 2025, and involved both lean individuals (BMI 18.5–24.9) and non-lean individuals (BMI >25). Participants were recruited through convenience sampling methods and were provided with small goodies as a gesture of appreciation. The participant group comprised university students, full-time employees, part-time employees and unemployed individuals. The data collection started with a setup meeting where participants met with the researcher to review the study’s design and procedures and to set up the necessary mobile applications. During this meeting, participants received an informed consent form, a detailed instruction manual, and an EmbracePlus wearable along with its charger. The researcher provided an overview of the study design and guided participants through downloading and setting up the TIIM and Care Lab applications, ensuring everything was properly configured.

Materials

EmbracePlus

The EmbracePlus is a wearable medical device designed to collect and analyse physiological data from the wrist, such as pulse rate, respiratory rate, electrodermal activity, and more. It connects to a companion app called Care Lab via Bluetooth to securely transmit data to the Empatica Cloud. The device features two dry electrodes for its EDA sensor (Empatica Inc., 2019). To ensure reliable physiological data collection, participants were instructed to minimize excessive hand movements and wear the device on the non-dominant wrist and positioned just above the wrist bone.

On the first day of data collection, participants wore the EmbracePlus continuously throughout the day but were permitted to remove it at night. On the second day, participants wore the EmbracePlus only during the VR experiment. After completing the VR session, participants were asked to sync their data using the Care Lab app before returning the EmbracePlus devices to the researchers.

Twente Intervention and Interactive Machine (TIIM) App

The use of mobile health (mHealth) technologies has been growing as a tool to collect health data, deliver healthcare information, and enable real-time monitoring of vital signs (Þórarinsdóttir et al., 2019). mHealth encompasses a range of tools, such as mobile phones, patient monitoring devices, and wireless sensors (WHO, n.d.). In this study, the TIIM App, developed by the BMS Lab, was utilised to implement the ecological momentary assessment (EMA) module (see Appendix F, Appendix G, and Appendix H). The TIIM App is a versatile mobile software designed to collect data directly from participants' smartphones (van 't Klooster et al., 2023). For this study, participants received four notifications at set times throughout the day, reminding them to complete the questionnaires and allowing for real-time data collection.

Stress in Action EMA

The Stress in Action EMA backbone was utilized in this study to evaluate stress and various factors related to stress research, such as self-perceived stress, affective states, cognitive appraisals or processing of stressful events, and coping strategies. Participants completed the questionnaires using the TIIM App (see Appendix F, Appendix G, and Appendix H). On Day 1, participants completed four questionnaires at different times, with notifications sent to their phones as reminders. The first notification for the initial questionnaire was sent at 7:00 AM and remained available until 12:00 PM. The second questionnaire was available between 1:00 PM and 3:00 PM, the third between 4:00 PM and 6:30 PM, and the final questionnaire between 8:00 PM and 11:30 PM. Participants were required to complete each questionnaire within its designated time slot. Examples of the Stress in Action EMA are “At this moment I feel stressed” (Not at all - Very much: 0-100), “Think about the most unpleasant situation since the last survey. This was a ….”, “Briefly describe this situation”, “How did you deal with this situation?”.

However, a potential limitation of the self-reported questionnaire data is its susceptibility to various biases. These include social desirability bias (faking good or faking bad), recall bias, and issues related to the complexity or ambiguity of certain questions, all of which can affect the accuracy and reliability of responses (Choi & Pak, 2005).

Care Lab App and Care Lab Portal

Participants were provided with QR codes, which they scanned using the Care Lab app to connect the EmbracePlus device to their phones. The app required both Bluetooth and an active internet connection and had to run in the background to facilitate data synchronization. It also provided participants access to basic measurements, such as heart rate and temperature. The researcher instructed participants on the correct placement of the wearable to ensure accurate data recording and checked that the devices were fully charged before starting the experiment on Day 2.

The Care Lab Portal allowed researcher to monitor participants' status and ensure proper data synchronization. The researcher reminded participants if the wearable was not being worn correctly or if data synchronization issues occurred. Digital biomarker data was initially stored in the Care Lab Portal, and raw data was downloaded using Cyberduck.

Data Analysis

EMA Data Processing

The EMA data was exported from TIIM in CSV format and imported into SPSS 29.0 for analysis. To answer research question 1, stress scores were calculated separately for daily life and laboratory settings, based on self-reported responses on a 0 to 100.

Daily life stress levels were computed by averaging responses to the following items:

- At this moment I feel stressed (core questionnaires 1 and 2)
- Today, I felt stressed (core evening questionnaire).

For stress levels in the laboratory setting, mean scores were computed from three items:

- How stressed do you feel about the upcoming VR experiment? (pre-questionnaire)
- How stressed did you feel during the VR experiment? (post-questionnaire),
- How stressed do you feel now after the VR experiment? (post-questionnaire).

To assess coping strategies, qualitative data was collected from the open-ended item "How do you plan to handle the stress you experienced?". Responses were thematically coded into categories through an inductive content analysis process, meaning categories were developed directly from the data based on similarities and patterns across responses, rather than being derived from pre-existing theoretical frameworks.

EDA Data Processing

Raw EDA data recorded using the EmbracePlus was accessed using an access key obtained from the Care Lab portal (Empatica, 2023) and downloaded via Cyberduck in AVRO file format. The data was then processed for analysis using Python. The data analysis for EDA in daily life started by converting raw AVRO files into CSV format for each participant. Furthermore, timestamps were adjusted from microseconds to hourly intervals and converted to Central European Time (CET). Once the data was cleaned to remove any missing data, it was divided into two folders for each participant category (lean and non-lean). Visualisations were created to show trends in EDA over time.

The data analysis for EDA in the laboratory condition began with filtering raw data from a combined CSV based on a specified Unix timestamp range. The timestamps were then converted to readable datetime format and localized to Central European Time (CET) and new CSV files were created. These files were organized into separate folders based on participant categories (lean and non-lean individuals). Mean EDA values were calculated for five task phases: Baseline, Phase 1 (Preparation Phase), Phase 2 (Speech Phase), Phase 3 (Arithmetic Task), and Recovery.

Results

Demographic

The analysis was conducted with a complete sample of 32 participants with an average age of 27.53 years. The sample comprised 14 females (43.8%) and 18 males (56.3%). A detailed overview of the sample can be found in Table 1.

Table 1

Overview of Participants' Demographics

Category	Description	Frequency	Percentage (%)
Gender	Female	14	43.8
	Male	18	56.3
BMI Category	Lean	17	53.1
	Non-Lean	15	46.9
Educational or Occupational Status	Foundation year	2	6.3
	Bachelor’s student	5	15.6
	Master’s student	19	59.4
	Part-time employee	3	9.4
	Full-time employee	2	6.3
	Unemployed	1	3.1

Research Question 1: Do individuals within this sample experience higher psychological stress levels in daily life or a controlled laboratory setting?

To examine differences in psychological stress levels between daily life and laboratory conditions, the mean stress scores for each participant were computed for both conditions. A paired samples t-test was conducted to compare the mean stress levels between daily life and the laboratory condition. The results of the paired samples t-test can be found in Table 2. No statistically significant difference was found between the two conditions (t = -0.813, p = 0.423), indicating that individuals did not experience significantly different stress levels in daily life compared to the lab, though participants experience greater psychological stress in their daily lives.

Table 2

Psychological Stress Levels Between Daily Life and Lab Conditions

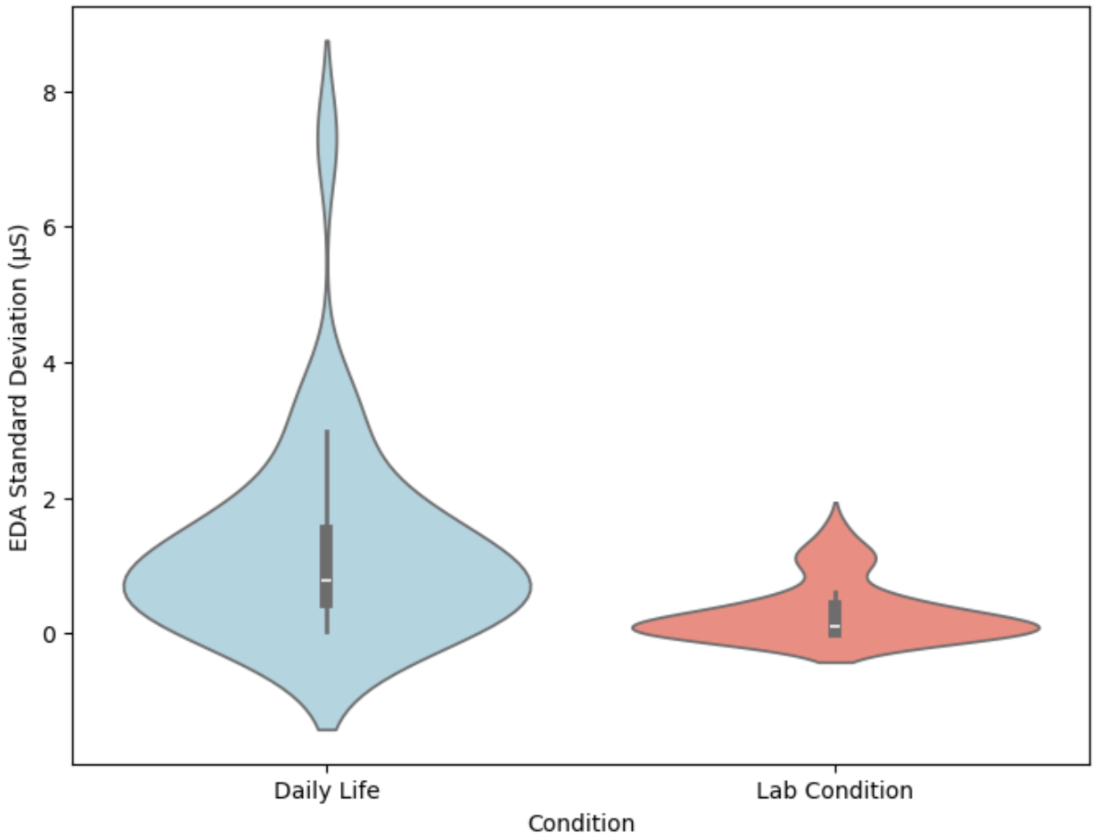
Condition	Mean	Standard Deviation	p
Daily Life	39.55	25.11859	.350
Lab Condition	35.88	19.74447	

Research Question 2: Do individuals within this sample exhibit greater electrodermal activity (EDA) variability in daily life compared to a controlled laboratory condition?

To examine differences in EDA variability between daily life and laboratory conditions, the standard deviation (STD) of EDA signals was computed for each participant in both conditions. A Wilcoxon Signed-Rank Test was conducted to compare the two conditions, as the data did not meet normality assumptions. The test showed a statistically significant difference in STD between daily life and laboratory condition (W = 45.00, p = 0.00), indicating that individuals exhibited greater EDA variability in daily life compared to the laboratory setting. The violin plot in Figure 4 further illustrates these differences. The daily life condition demonstrated a wider spread of standard deviations, indicating a larger range of variability across participants. In contrast, the laboratory condition showed lower and more consistent EDA variability. The plot also suggests that a few participants exhibited particularly high EDA variability in daily life.

Figure 4

Comparison of EDA Variability in Individuals Between Daily Life and Lab Condition

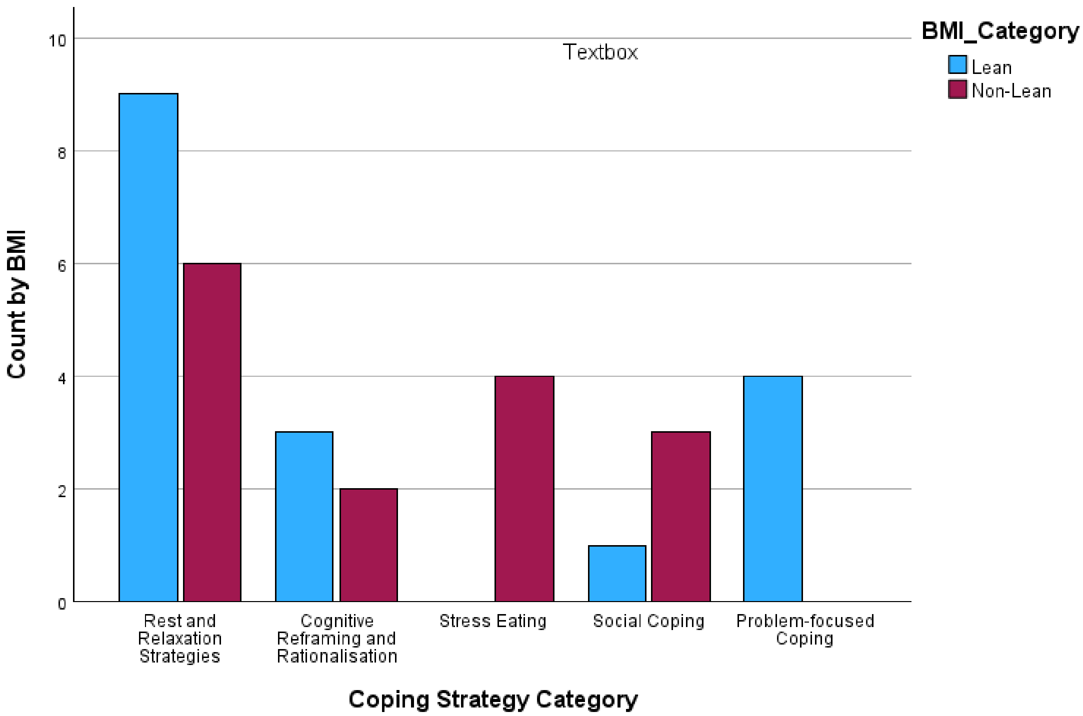


Research Question 3: How do lean and non-lean individuals differ in their coping strategies after experiencing a stressful laboratory condition?

Rest and relaxation strategies, such as deep breathing and meditation, are used more frequently by lean individuals, along with problem-focused coping. In contrast, stress eating was exclusively reported by non-lean individuals, suggesting a potential reliance on food as a coping mechanism. They also use social coping, such as seeking support from others, more frequently than lean individuals. See Appendix J for a detailed overview of the coping strategies used by each participant and their categorisation.

Figure 6

Coping Strategy Category by BMI



Research Question 4: Is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals during daily life condition within this sample?

To investigate whether electrodermal activity (EDA) is higher in non-lean individuals compared to lean individuals during daily life condition, the mean EDA was computed for each participant. A Shapiro-Wilk test was performed to assess normality, and the data did not meet normality assumptions. The results showed that the mean EDA for lean individuals was 0.55, while the mean EDA for non-lean individuals was 2.55. The Mann-Whitney U test indicated no statistically significant difference between the groups ($U = 89.00$, $p = 0.1513$), suggesting that EDA levels during daily life were not significantly higher in non-lean individuals compared to lean individuals.

Research Question 5: Is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals under lab-controlled condition within this sample?

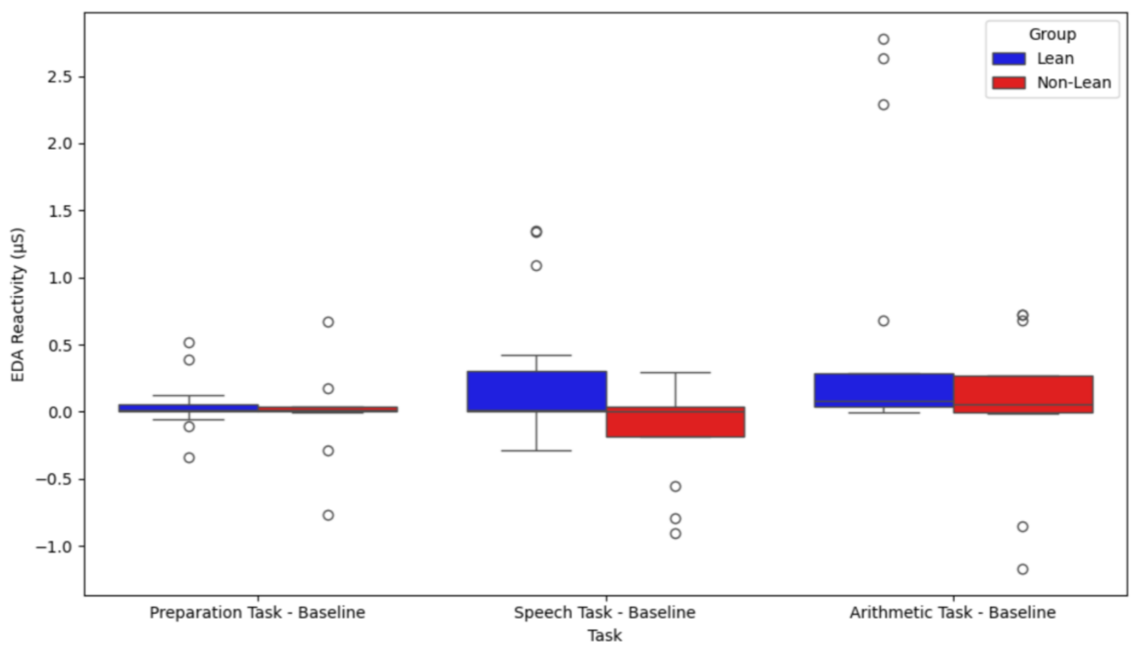
To examine whether non-lean individuals exhibited higher electrodermal activity (EDA) than lean individuals under lab-controlled conditions, mean EDA was compared between the two groups. A Mann-Whitney U test indicated that the difference was not statistically significant ($U = 146.00$, $p = 0.2483$). However, descriptively, non-lean individuals showed a higher average EDA ($M = 1.33$) compared to lean individuals ($M = 0.88$).

Research Question 6: Do Lean individuals exhibit higher EDA reactivity than Non-Lean individuals during each stress tasks?

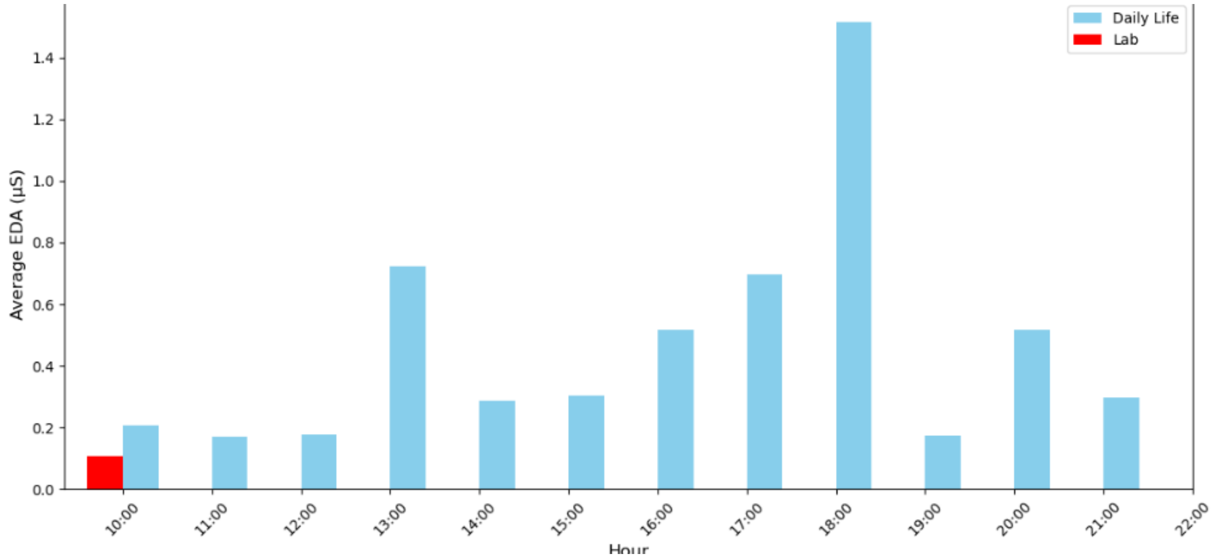
During the Preparation Task, both groups exhibit minimal EDA reactivity with low variability. However, in the Speech Task, the lean group shows a higher median EDA reactivity compared to the non-lean group, with greater variability in responses. In contrast, the Arithmetic Task presents a more balanced distribution between the two groups, with overlapping medians.

Figure 7

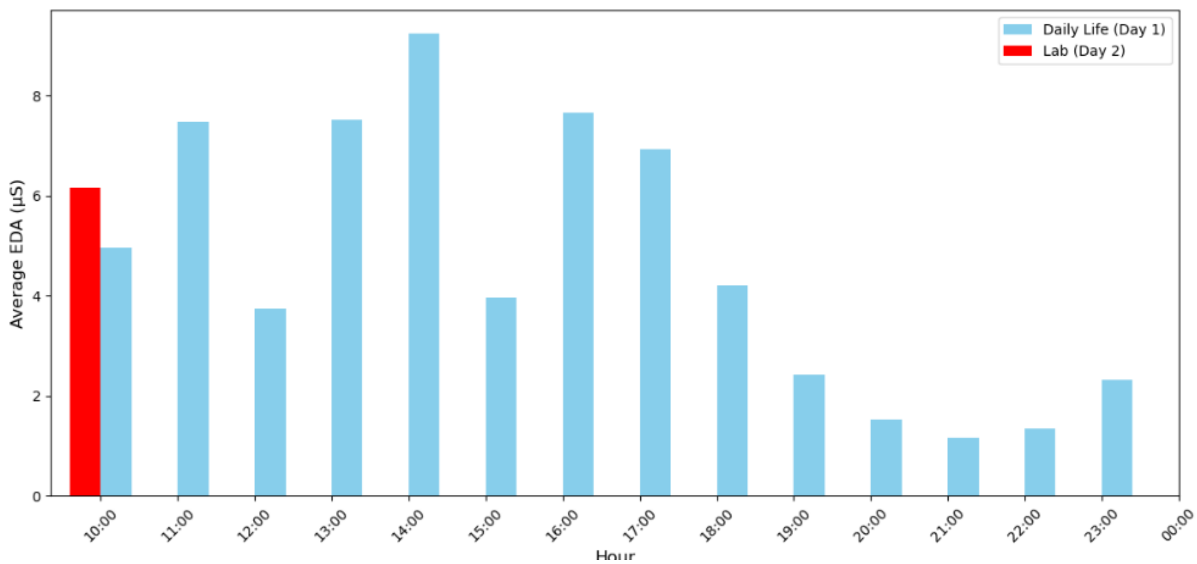
EDA Reactivity Across Different Tasks for Lean and Non-Lean Groups



Example of Mean EDA Across Participant Categories and Conditions



a. Mean EDA of A Lean Individual in Daily Life and Lab Condition



b. Mean EDA of A Non-Lean Individual in Daily Life and Lab Condition

Discussion

Summary of Key Findings

This study aimed to explore the psychological stress level and EDA differences between lean and non-lean individuals in two conditions: daily life and laboratory control. Results revealed that individuals have higher psychological stress levels and greater EDA variability in their daily lives compared to laboratory setting. This highlights the dynamic and context-dependent nature of stress responses shaped by both environmental factors and individual characteristics. While these findings demonstrate the influence of situational stressors, individual differences such as body composition may further contribute to variations in stress reactivity and coping mechanisms.

When comparing lean and non-lean individuals, non-lean participants consistently exhibited higher mean EDA levels in both daily life and laboratory conditions. Although these differences did not reach statistical significance, the consistent trend of higher EDA levels in non-lean individuals aligns with prior research suggesting a potential link between stress and obesity. Furthermore, only non-lean individuals within this sample reported stress eating as a coping strategy, suggesting differences in how body composition may influence coping mechanisms under stress.

By integrating EMA with wearable EDA data, this study provides a more holistic understanding of stress that goes beyond solely relying on physiological or self-reported measures. Capturing psychological and physiological responses across diverse real-world and controlled environments allows for a more nuanced perspective on how stress manifests and is regulated in individuals with different body compositions.

Do individuals within this sample experience higher psychological stress levels in daily life or a controlled laboratory setting?

Although participants reported slightly higher perceived stress levels in daily life compared to the lab, this difference was not statistically significant. This finding was based on data collected through Ecological Momentary Assessment (EMA) in daily life and stress measurements in the controlled laboratory environment. EMA methods provide valuable insights into real-time fluctuations in psychological states, such as changes in mood, energy, and burnout, and how these changes influence perceived stress (Mengelkoch et al., 2023). By capturing these dynamic processes across days, EMA helps uncover temporal relationships between psychological mechanisms and health-related outcomes. However, in this study, participants were only asked to complete EMA assessments for a single day, which limits the ability to capture the full complexity and variability of real-world stress. This limited data collection period could be one plausible reason why the results did not reach statistical significance. Furthermore, Epel et al. (2018) emphasised that fully understanding stress and its effects requires not only examining individual stressors and responses but also considering the broader context in which they occur—including personal histories, environmental factors, and available coping resources. Without this contextual understanding, the true nature of stress exposure and response can be easily misinterpreted.

Further illustrating the role of context, Piazza et al. (2013) highlighted that daily stressors consist of both predictable and unpredictable events, which can disrupt daily routines and gradually contribute to overall stress levels. This reinforces the importance of capturing the full range of daily experiences, not just isolated moments of peak stress. This variability was further reflected in the EMA data itself, where some participants reported experiencing no unpleasant events or stressful situations during their daily assessment period, resulting in low reported stress levels. Such differences in daily experiences underscore the need for extended monitoring to capture a more comprehensive picture of stress exposure and its long-term effects.

Given the limitations in assessing psychological stress, it is also crucial to examine whether physiological stress markers, such as electrodermal activity (EDA) differ between contexts. Since stress responses are dynamic and shaped by both environmental and individual factors, fluctuations in EDA may provide additional insights into how stress manifests beyond self-reported measures.

Do individuals within this sample exhibit greater electrodermal activity (EDA) variability in daily life compared to a controlled laboratory condition?

In contrast to the variability and unpredictability of daily life stress, the laboratory environment provided an artificial stressor, which may explain why participants reported lower perceived stress levels in the lab. Many participants were aware that the laboratory stressor was temporary and not a real threat, which likely reduced its perceived severity. This is supported by post-questionnaire responses: *"I'm aware that VR is not real, and I'm in a safe environment", "I'm not dealing with real-life stress, so I can relax", "Probably the same as before—just pretending it's not there. Since I know it's fake, I'm not stressed".*

Although perceived stress levels did not differ significantly between daily life and the lab, electrodermal activity (EDA) showed significantly greater variability in daily life compared to the controlled laboratory environment. This aligns with a study from De Calheiros Velozo et al. (2023) who found that self-reported stress levels (perceived stress) were only weakly related to physiological stress responses. This suggests that even when individuals report low stress levels, their bodies might react differently and might still exhibit heightened physiological stress responses.

This finding also highlights that physiological stress levels in a laboratory setting do not fully reflect the dynamic and fluctuating nature of stress experienced in real-world conditions. The observed difference in EDA variability between daily life and the laboratory can be attributed to several factors. First, the duration of data collection differed substantially between conditions. In daily life, EDA was collected over a much longer period (10:00 to 00:00), whereas the laboratory experiment lasted only 25 minutes. The data from daily life allows for more opportunities to capture fluctuations in stress levels in daily life. This aligns with (Epel et al., 2018), who emphasized that an individual's life context, including chronic stressors, influences the frequency of daily stressors, emotional reactivity, and recovery. Moreover, real-life stress tends to be more unpredictable and context-dependent than stress experienced in controlled settings (Epel et al., 2018).

Second, the nature of the laboratory environment may contributed to the reduced EDA variability. Laboratory experiments are in controlled conditions and are typically done in a quiet and unfamiliar environment, which may not fully capture the complexity of real-life stressors (Can et al., 2019). This is further supported by Fallon et al. (2021) who found that VR TSST elicits a weaker autonomic response compared to in vivo TSST.

Another plausible explanation is the difference in energy expenditure between the two conditions. Ji et al. (2019) found that EDA positively correlates with energy expenditure during movement, with more intense motion leading to stronger correlations. In daily life, participants engaged in various activities such as biking, walking, and running, whereas in the VR laboratory experiment, they remained seated with minimal movement, likely contributing to differences in EDA patterns (Can et al., 2019).

Finally, environmental and physiological factors such as body temperature also differed between the two conditions. In daily life, body temperature varies more due to physical activity and environmental temperature fluctuations. In contrast, the laboratory setting had a consistent room temperature, leading to more stable body temperatures across participants. This aligns with findings from Li et al. (2022) which highlight the impact of environmental and physiological factors on EDA and stress responses.

How do lean and non-lean individuals within this sample differ in their coping strategies after experiencing a stressful laboratory condition?

While EDA reactivity offers important insights into the physiological stress responses of lean and non-lean individuals, coping strategies provide a psychological perspective on how they handle stress. Coping strategies can be categorized into adaptive and maladaptive. Adaptive strategies include problem-focused coping (e.g., active coping, planning), emotion-focused coping (e.g., positive reframing, acceptance), meaning-focused coping (using cognitive strategies to find meaning), and social coping (seeking support from others). Meanwhile, maladaptive strategies involve behaviours such as overeating, smoking, drinking, and drug use, which are linked to negative outcomes like depression, pain, and lower self-efficacy (Javed & Parveen, 2021).

Lean individuals within this sample tend to use adaptive coping strategies by relying more on rest and relaxation, as well as problem-focused coping. In contrast, non-lean individuals reported engaging in maladaptive coping strategies, and stress eating which was not found in lean individuals, suggesting a potential reliance on food as a coping mechanism. This finding was supported by Nightingale and Cassin (2019) and van Strien (2018) who highlighted that overweight and obese individuals are more likely to engage in emotional eating, as certain foods can help relieve negative emotions like sadness and enhance positive feelings. Given these differences, it is also important to explore whether they also manifest in physiological stress markers, such as electrodermal activity (EDA).

Is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals during daily life conditions within this sample? And is electrodermal activity (EDA) higher in non-lean individuals compared to lean individuals under lab-controlled conditions within this sample?

Stressors not only influence coping strategies but also impact physiological responses, which can vary among individuals, including differences between lean and non-lean individuals. This study found that non-lean individuals consistently exhibited higher electrodermal activity

(EDA) levels than lean individuals across both daily life and laboratory conditions, suggesting that higher BMI may be associated with an altered physiological stress response. This is consistent with previous research by Verdejo-Garcia (2019) which found that overweight and obese individuals experience stronger physiological reactions to acute stressors, which can negatively impact cognition.

EDA reflects sympathetic nervous system (SNS) activation, which triggers the "fight or flight" response under stress. This process increases sweat gland activity, leading to changes in skin conductance (Pop-Jordanova & Pop-Jordanov, 2020; van der Mee et al., 2021). Loffler et al. (2002) found that individuals with higher BMI tend to have larger skin folds, increased blood flow, and elevated blood pressure, all of which contribute to greater sweat gland activity. Yosipovitch et al. (2007) and Loffler et al. (2002) further highlighted that obesity is associated with altered skin physiology which leads to more sweating even during resting conditions. However, it is important to note that in this study, the difference in EDA levels between lean and non-lean individuals did not reach statistical significance. This suggests that while there may be a trend toward heightened physiological arousal in non-lean individuals, the relationship may be more complex and influenced by additional factors, such as individual differences in stress perception, environmental conditions, physical activity, and body temperatures (Can et al., 2019; Epel et al., 2018; Ji et al., 2019; Li et al., 2022). Furthermore, despite higher average EDA levels, non-lean individuals may exhibit reduced EDA variability due to dysfunction in autonomic nervous system reactivity.

Do lean individuals exhibit higher EDA reactivity than non-lean individuals during each stress task?

After examining the differences in EDA between lean and non-lean individuals, this study also tried to explore how these differences are expressed across various stress-inducing tasks, particularly in a controlled laboratory setting. This study found that EDA reactivity varies across tasks, with the Speech Task eliciting the most pronounced response, particularly among lean individuals (see Figure 7). The lower EDA reactivity observed in Non-Lean individuals may indicate differences in stress regulation or autonomic response patterns. This finding aligns with de Geus et al, (1993) who found that physiological characteristics (fitness or body composition) do not straightforwardly predict lower stress reactivity.

Strengths and Limitations

One key strength of this study is the use of EMA three times a day, which captured participants' experiences in their natural environment. This method enhances ecological validity by minimizing recall bias and providing a more accurate representation of fluctuations in stress levels and responses. This strength is supported by Mengelkoch et al. (2023) who emphasized that EMA enables researchers to assess daily fluctuations in psychological states. Additionally, the combination of laboratory and real-world data offers a comprehensive understanding of stress responses. The controlled laboratory setting allows for precise measurement of physiological stress markers, while real-world data captures how stress manifests in daily life, providing ecologically valid insights. Lastly, by comparing physiological stress responses and coping strategies between lean and non-lean individuals, this research can inform public health interventions aimed at promoting healthier coping mechanisms.

However, this study also has some limitations. One most notable limitation is the sample size in this study is relatively small (n = 32) and predominantly comprised of university students who more or less experience the same stressors. This could limit the generalizability of the results as stress perception and physiological responses can vary across different age groups, socioeconomic backgrounds, or individuals with chronic health conditions. Therefore, future studies should aim for a more diverse and representative sample to strengthen the external validity of the findings. Furthermore, the laboratory experiment did not account for whether participants consumed caffeine, drugs, or medications, which could influence their physiological stress responses. This discrepancy could introduce uncontrolled variables affecting the comparability between laboratory and real-life stress responses. Future studies should collect pre-experiment data on participants' consumption of substances that may influence stress responses.

Another limitation is the lack of data on participants' physical activity levels, despite evidence suggesting that physical activity can influence skin conductance responses. Since EDA is closely linked to movement and energy expenditure, the lack of physical activity data could limit the interpretation of stress-related physiological changes (Hu et al., 2024). Lastly is the use of BMI as the sole indicator of obesity. While BMI is commonly used to classify obesity, it does not fully capture body composition, fat distribution, or metabolic health. Therefore, more precise measures, such as body fat percentage or waist-to-hip ratio, could provide a more comprehensive understanding of how obesity influences stress reactivity (Hu et al., 2024).

Conclusion

This study explored psychological stress levels, electrodermal activity (EDA), and coping strategies among lean and non-lean individuals in both daily life and laboratory settings. While participants reported slightly higher stress levels in daily life, this difference was not statistically significant, possibly because the laboratory environment was perceived as artificial and temporary. However, EDA variability was statistically significantly greater in daily life, highlighting the complex and dynamic nature of real-world stressors.

Non-lean individuals exhibited higher mean EDA in both settings, suggesting a link between higher BMI and altered physiological stress responses. Additionally, non-lean individuals exhibited maladaptive coping strategies, particularly stress eating, which was not observed in lean individuals. In contrast, lean individuals tended to rely more on adaptive coping strategies, such as problem-focused coping and relaxation. These findings underscore the potential influence of body composition on both physiological responses and coping mechanisms under stress.

A notable innovation from this study is its ability to bridge real-world and laboratory stress responses through the use of VR and ambulatory monitoring. By integrating Ecological EMA, wearable devices, VR testing, and daily life measurements into a single comprehensive research design, this study offers a richer and more holistic understanding of stress responses. This study also captures both subjective and objective data across controlled and natural environments.

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Appendix A - Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves answering a set of questionnaires, wearing a wearable device for two days, and undergoing a VR experiment.	□	□
Risks associated with participating in the study		
I understand that participating in the study involves certain risks, including experiencing psychological discomfort from a brief and intense stressful situation caused by the stimuli presented in the VR environment.	□	□
Use of the information in the study		
I understand that the information I provide will be used anonymously for research purposes and analysis in a future research project.	□	□
I understand that the data will be stored securely, and any publications or reports resulting from this study will exclude information that could reveal the identity of participants and will be kept confidential within the research team.	□	□
Future use and reuse of the information by others		
I agree that my information may be shared with other researchers for future research studies that may be similar to this study. The information shared with other researchers will not include any information that can directly identify me.	□	□
I give permission for the data that I provide to be archived in Areda, the UT Archive for Research Data, so it can be used for future research and learning	□	□

Signatures

________________________	________________________	_________
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands what they are freely consenting.

Researcher name Signature Date

Study contact details for further information:

Gita

nimadegitaananditadewi@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

Appendix B - Experiment Overview and Instructions

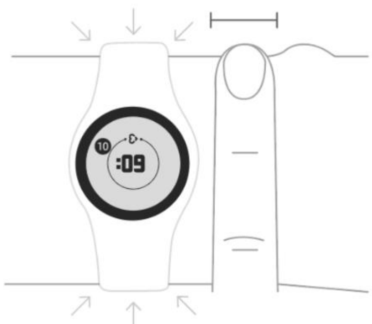
About the Study

This study aims to explore physiological and psychological stress responses in daily life and under laboratory conditions. You will be wearing the Embrace Plus wearable device, which records:

- Electrodermal activity (EDA): Measures sweat levels on your skin.
- Heart rate

These biomarkers are key indicators of stress and will help us understand stress responses in different environments.

Device Setup and Usage



1. **Wear Placement**:
   - Wear the Embrace Plus device on your **non-dominant hand** to minimize movement and ensure reliable data.
   - The **watch face** should be on the **dorsal side** (back of your hand), about **an index finger's width from the wrist bone**.
2. **Securing the Device**:
   - Fasten the band snugly so the device does not move freely.
   - Ensure the sensors on the underside are in **full contact** with your skin.
3. **Sensor and Band Holder Placement**:
   - Do not let the **band holder or free loop** cover the **EDA sensors** (the two metal electrodes) located near the buckle of the device.
4. **Sensor Checks**:
   - The **green light** from the PPG sensor LEDs on the underside of the device should not be visible on your skin. Ensure the green light is completely covered by the device.
5. **Waterproof Guidelines**:
   - Embrace Plus is waterproof and can be worn during exercise and showers.
   - **Do not wear** the device while swimming in saltwater, or while using a **hot tub, sauna, or steam room**.

    - Avoid submerging the device in water deeper than **3.3 feet (1 meter)** for longer than **30 minutes**.
6. **Charging**:
    - Charge the device **overnight before Day 2** to ensure sufficient battery for the experiment.

You will also receive a **PDF manual** with detailed instructions for using the Embrace Plus device.

Schedule and Activities

Day 0: Initial Setup (on campus)

- 45 minutes
- Install the *Care Lab* app on your phone and connect the *Embrace Plus* to it.
- Install the *TIIM* app on your phone.
- Create an account and enter the voucher code or scan the QR code to join the study

VOUCHER CODE

Ey0oY

- Review and sign the informed consent.

Day 1: Full-Day Wearable Monitoring (at home)

- Wear the Embrace Plus device throughout the day.
- Complete four questionnaires on the *TIIM* app according to the following schedule:
    - **07:00 - 12:00** (First Questionnaire, ~5 minutes).

- **13:00 - 15:00** (Second Questionnaire, ~10-15 minutes).
- **16:00 - 18:30** (Third Questionnaire, ~10-15 minutes).
- **20:00 - 23:30** (Fourth Questionnaire, ~10-15 minutes).

⚠️ Questionnaires are only available during their specific time windows and cannot be completed afterwards.

Important: Please always turn your **Bluetooth ON and** keep the **Care Lab app** open in the background on your phone to ensure that data from the Embrace Plus device is syncing properly.

Day 2: Virtual Reality Session (on campus - BMS Lab, Langezijds 1501)

- Participate in the **Virtual Reality experiment** for approximately 1 hour.

Returning the Device

After completing the experiment on **Day 2**, please return:

1. The **Embrace Plus device**.
2. The **box**, including the **charger** and **manual**.

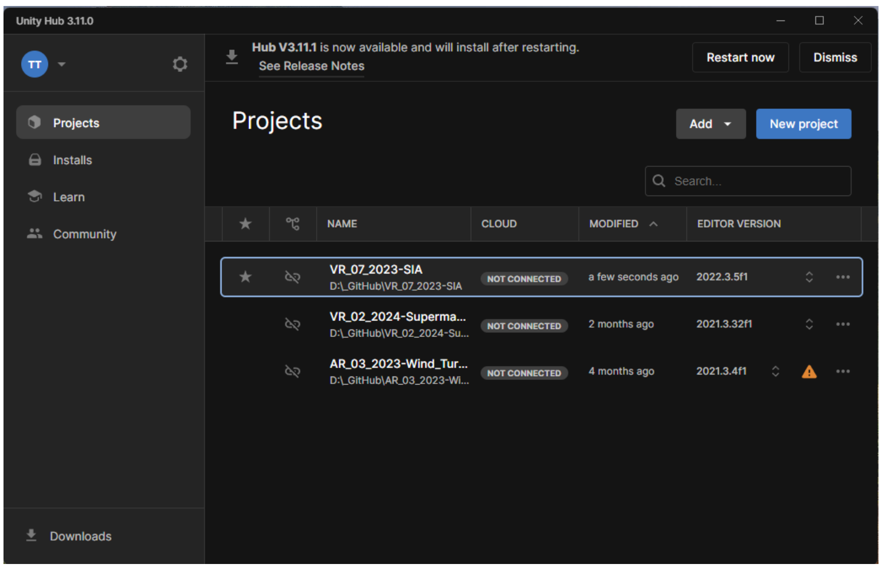
Thank You for Your Participation!

Appendix C - VR TSST and Occulus Quest Set Up

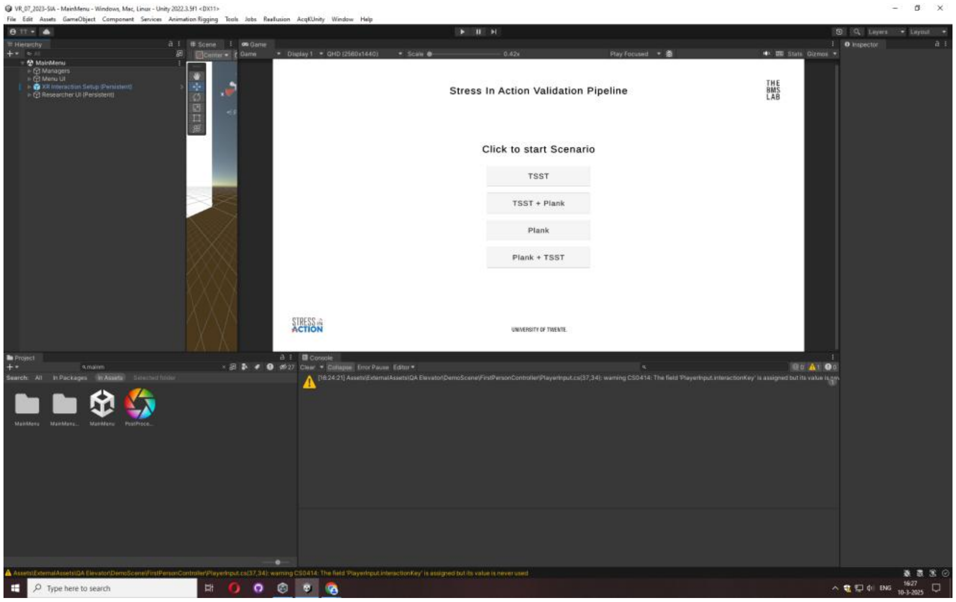
1. Setting Up VR TSST

1.1 Open the Unity Application

1.2 Go to “Project” and Click on the “VR_07_2023-SIA” and Unity Hub will open



1.3. Click on the play button and the TSST scenario.

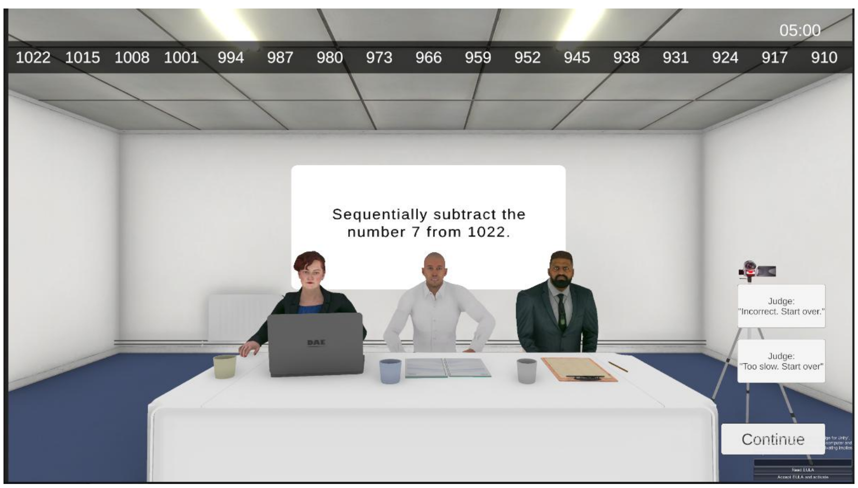


1.4. The Virtual Agent will show up and give instructions

1.5. The first phase (Preparation phase) will automatically starts after the virtual agent finish explaining the tasks.

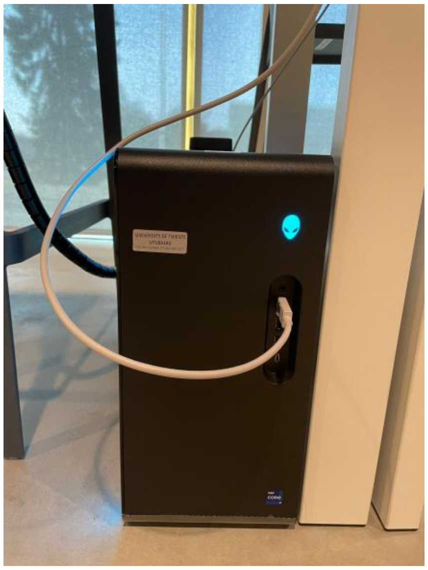
1.6. After five minutes have passed, the next phase (Speech Task) will automatically start.

1.7. Phase 3 (arithmetic task) will automatically start after phase 2 ends.

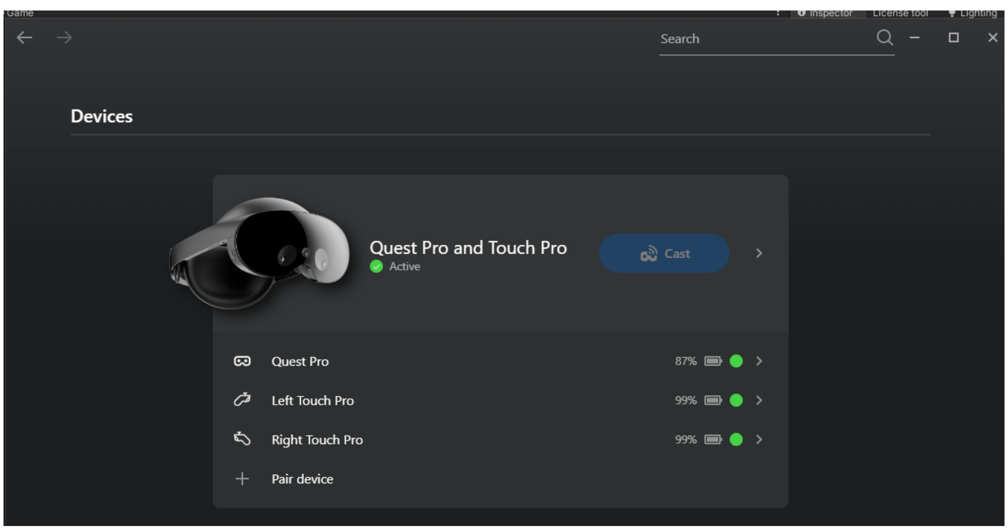


2. Setting up Meta Quest 2

2.1. Make sure the cable are connected to the computer and to the Oculus Quest Pro / Oculus Quest 3



2.2. Open the “Meta Quest Link” application



2.4. Oculus Quest is ready to use

Appendix D - VR TSST Protocol

1. **Participant Arrival and Setup**
   - Participants arrive at the lab.
   - The researcher ensures participants wear the Embrace Plus correctly.
   - The researcher checks that the Oculus Quest Pro or 3 headset and the VR TSST system are functioning properly.
   - The researcher prepares an Excel sheet to track the timing of each phase in the experiment.
2. **Pre-test**
   - Participants complete the pretest questionnaire on the TIIM App.
3. **VR TSST Procedure**
   a. **Baseline**
      - Participants walk up and down the stairs three times
      - Participants return to the XR Lab and sit for five minutes.
      - Participants wear the Oculus Quest headset.
      - The researcher write down the start time

   b. **Preparation Phase**
      - The virtual agent provides instructions for a five-minute interview.
      - The researcher write down the start time

   c. **Speech Task**
      - Participants speak for five minutes
      - The researcher clicks prompts to guide them such as “You still have time remaining” and “Ok, that’s enough. Please proceed with the weaknesses”.
      - The researcher write down the start time

   d. **Arithmetic Task**
      - Participants receive instruction from the virtual agent to subtract 7 from 1022 as quickly and accurately as possible.
      - Participants are required to start over if they make mistakes or are too slow.
      - The researcher monitors responses and clicks prompts such as “Incorrect. Start over” or “Too slow. Start over”.

- The researcher write down the start time

e. Recovery

- Participants sit for five minutes.
- The researcher write down the start time

4. Post-test

- Participants complete the final questionnaire on the TIIM App.
- Participants open the Care Lab App, click on log out sync data, and return the Embrace Plus.

5. Session Conclusion

- The researcher ends the session.
- The researcher exports data and shuts down all equipment

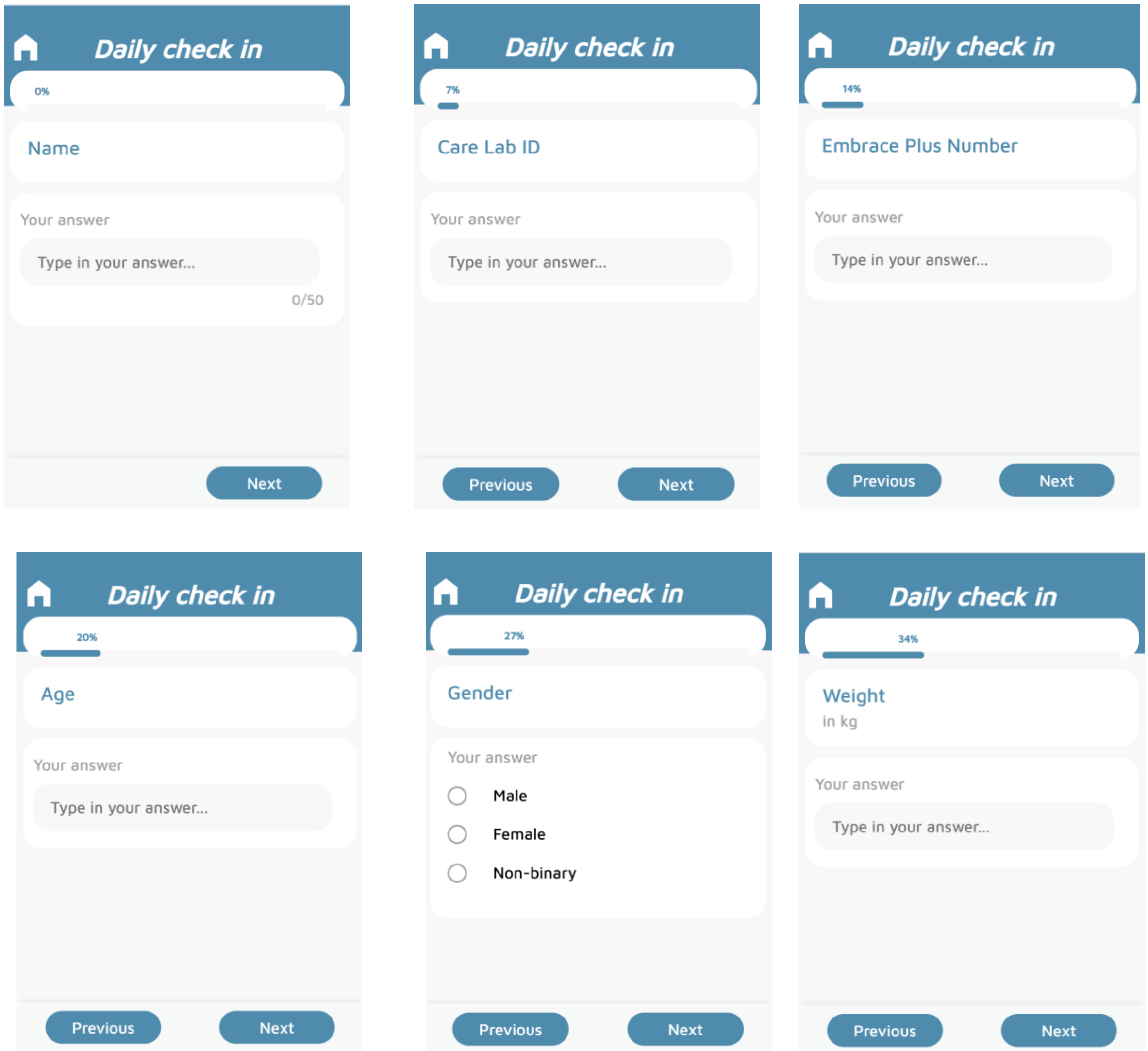
Appendix E - Thesis Experiment Protocol

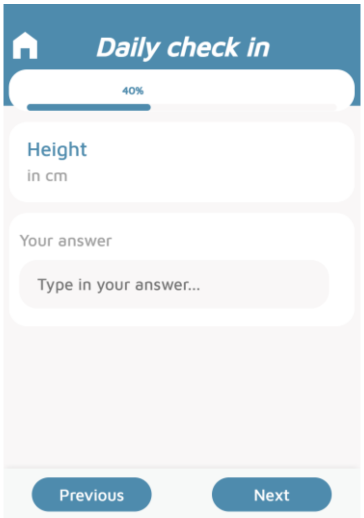
Day	Activity	Description	Time log	Notes
Day 0	Before the experiment	Participants come to the laboratory to get their Embrace Plus and enroll on the study on the TIIM App		
		Participants download the Care App and TIIM App		
		Researcher prepares a QR code for participants to scan, enabling them to connect the Embrace Plus device to the Care App and help to sync the data		
		Researcher gives the voucher code on the TIIM App to the participants		
		Researcher explains the experiment and provides informed consent		
Day 1	Coreset Questionnaire on the TIIM App	Participants fill in the questionnaire on the TIIM App (4 times a day)		
		Core questionnaire items: morning and evening		
	Embrace Plus	Participants wear the Embrace Plus continuously throughout the day		
Day 2	Before the VR experiment	Researcher ensures the Oculus Quest 2 headset and the VR TSST works		

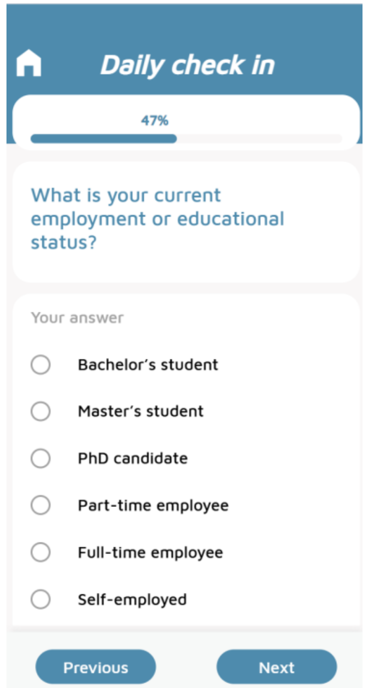
		Researcher prepares an Excel sheet to track the timing of each phase in the VR experiment		
	Pre-test	Participants complete the Coreset questionnaire on the TIIM App and wear the Embrace Plus		
	Baseline Measurement	Participants go up and down the stairs 3 times		
		Participants go back to the XR Lab and sit for 5 minutes, then wear the Oculus Quest 2 headset		
	Phase 1: Preparation	Participants receive instructions from the virtual agent to prepare for a 5-minute interview		
	Phase 2: Job Interview	Participants speak for 5 minutes; the researcher clicks prompts to guide them		
		Panel encourages them to say more, using scripted prompts		
	Phase 3: Arithmetic Task	Participants subtract 7 from 1022 quickly and accurately; mistakes require restarting		
		Researcher monitors answers and clicks prompts for errors or task completion		
	Recovery Phase	Participants sit for 5 minutes		
	Post-test	Participants complete the questionnaire on the TIIM App		
	Close up	Participants return the Embrace Plus		

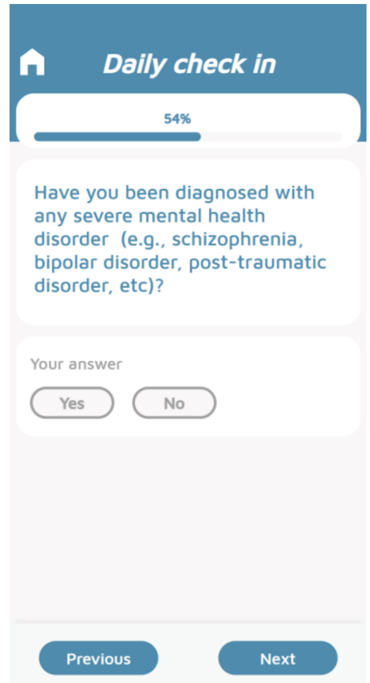
		Researcher ends the session, exports data, and shuts down equipment		

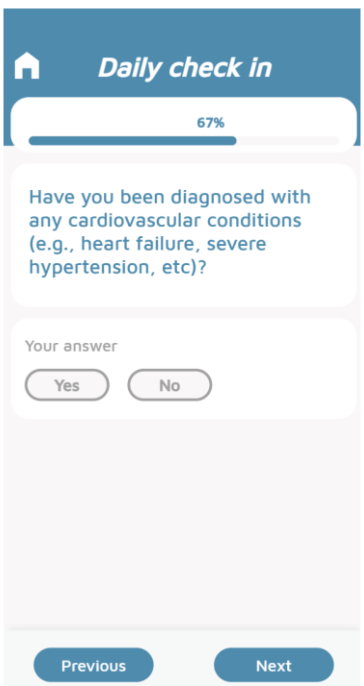
Appendix F - Demographic Questionnaire

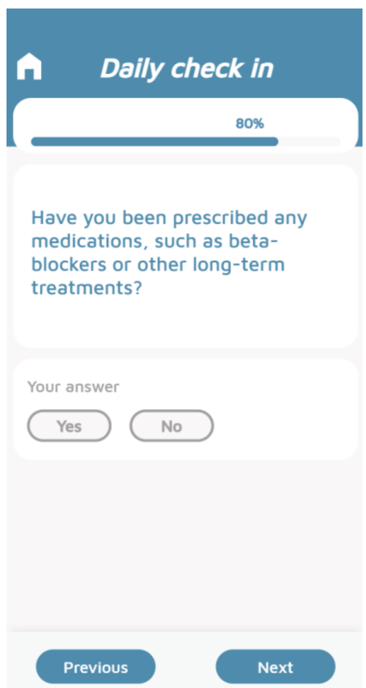



Daily check in
40%
Height
in cm
Your answer
Type in your answer...
Previous
Next

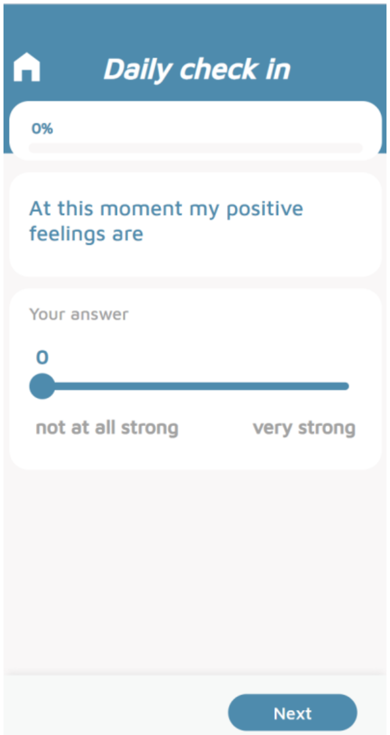

Daily check in
47%
What is your current employment or educational status?
Your answer
Bachelor's student
Master's student
PhD candidate
Part-time employee
Full-time employee
Self-employed
Previous
Next

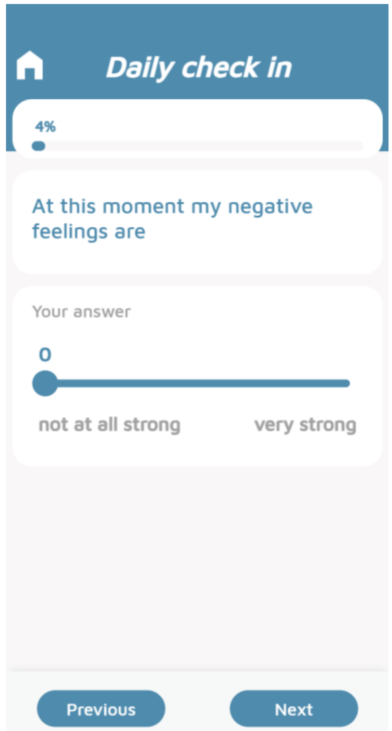

Daily check in
54%
Have you been diagnosed with any severe mental health disorder (e.g., schizophrenia, bipolar disorder, post-traumatic disorder, etc)?
Your answer
Yes
No
Previous
Next

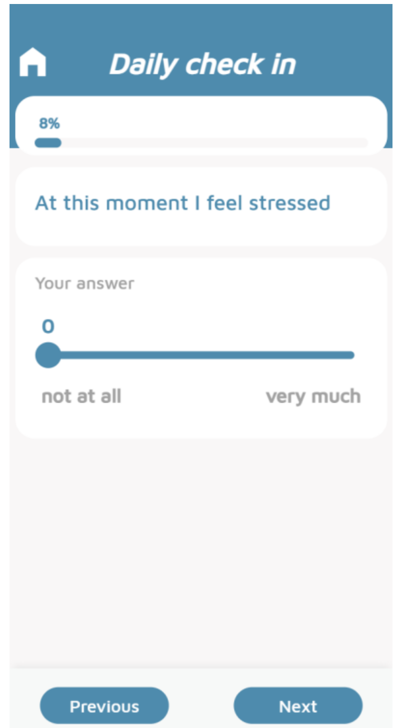

Daily check in
67%
Have you been diagnosed with any cardiovascular conditions (e.g., heart failure, severe hypertension, etc)?
Your answer
Yes
No
Previous
Next

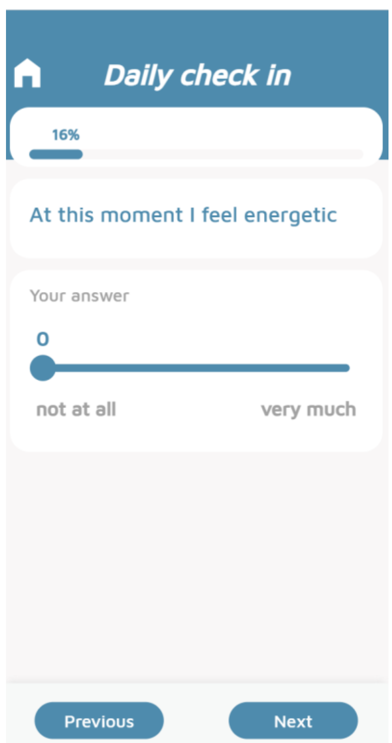

Daily check in
80%
Have you been prescribed any medications, such as beta-blockers or other long-term treatments?
Your answer
Yes
No
Previous
Next

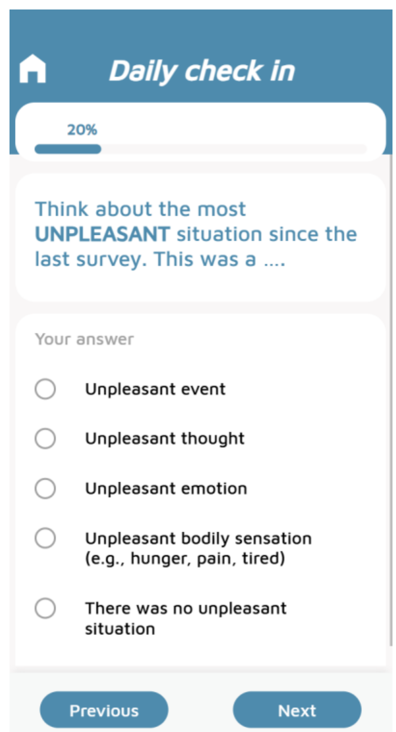
Appendix G - Stress in Action EMA Core Questionnaires 1 and 2

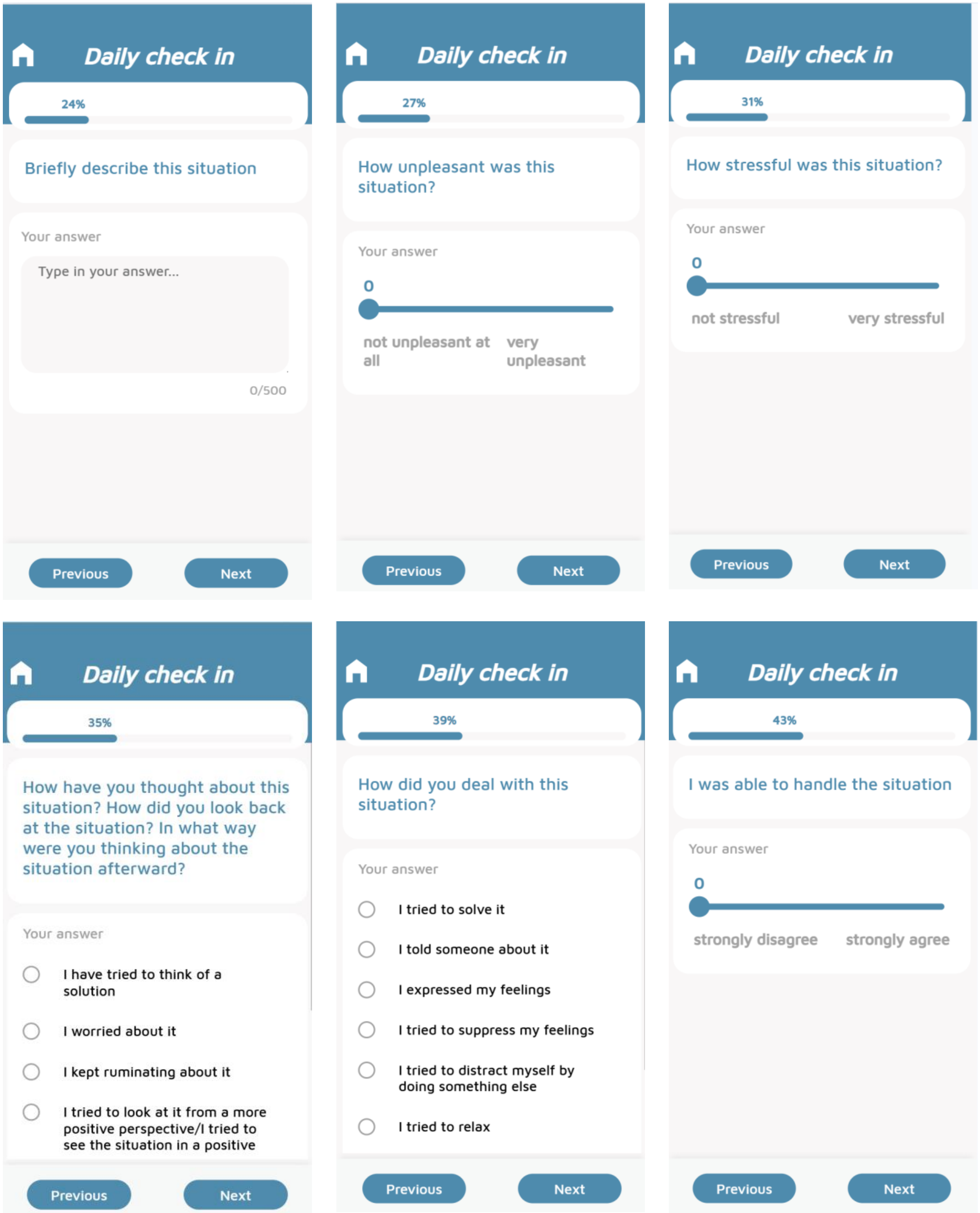


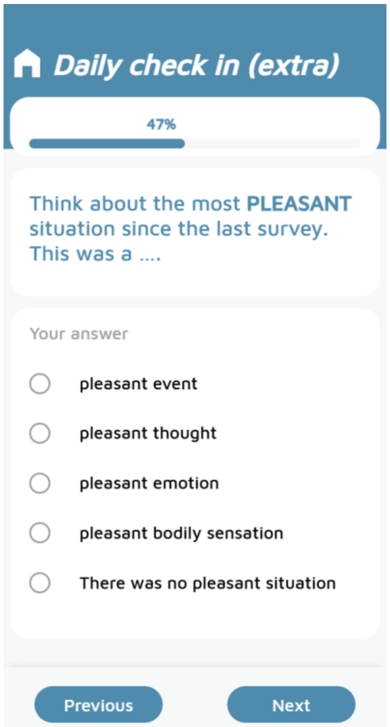


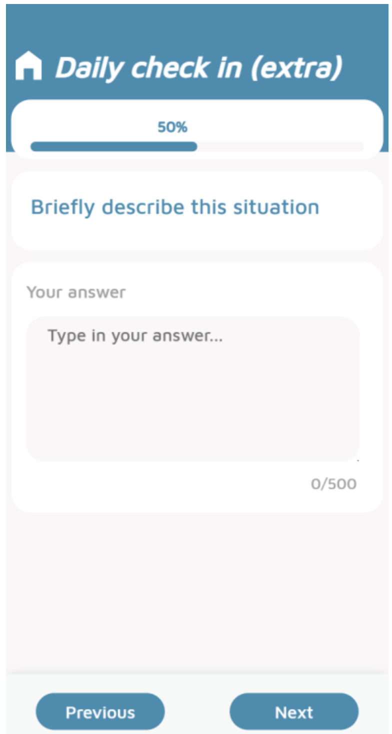


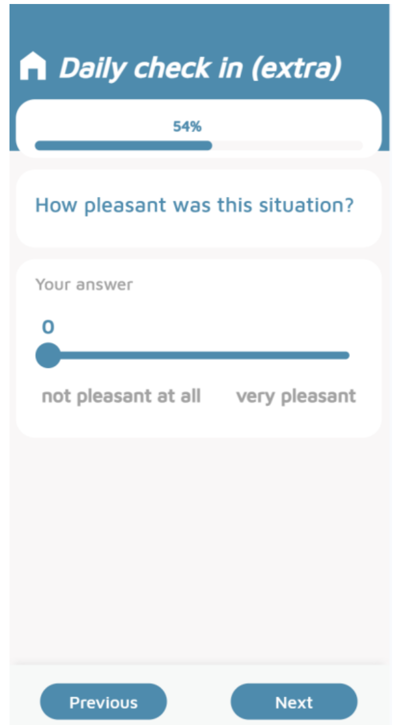


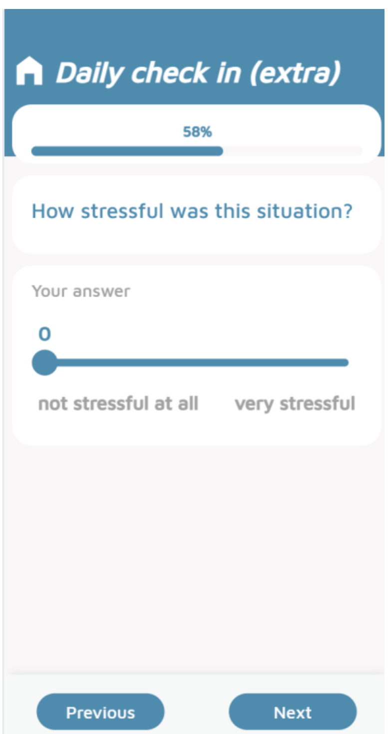


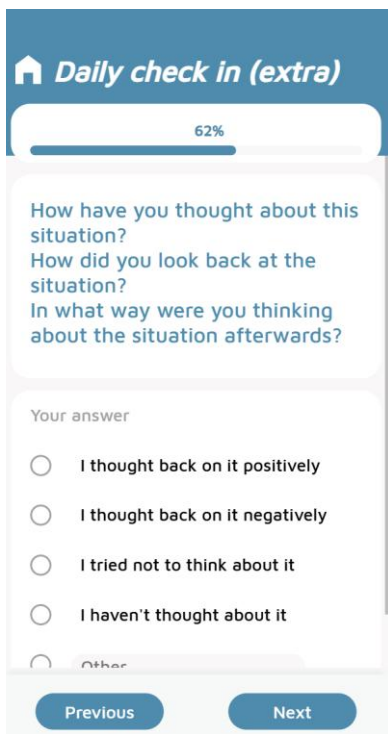

Daily check in
24%
Briefly describe this situation
Your answer
Type in your answer...
0/500
Previous
Next
Daily check in
27%
How unpleasant was this situation?
Your answer
0
not unpleasant at all
very unpleasant
Previous
Next
Daily check in
31%
How stressful was this situation?
Your answer
0
not stressful
very stressful
Previous
Next
Daily check in
35%
How have you thought about this situation? How did you look back at the situation? In what way were you thinking about the situation afterward?
Your answer
I have tried to think of a solution
I worried about it
I kept ruminating about it
I tried to look at it from a more positive perspective/I tried to see the situation in a positive
Previous
Next
Daily check in
39%
How did you deal with this situation?
Your answer
I tried to solve it
I told someone about it
I expressed my feelings
I tried to suppress my feelings
I tried to distract myself by doing something else
I tried to relax
Previous
Next
Daily check in
43%
I was able to handle the situation
Your answer
0
strongly disagree
strongly agree
Previous
Next

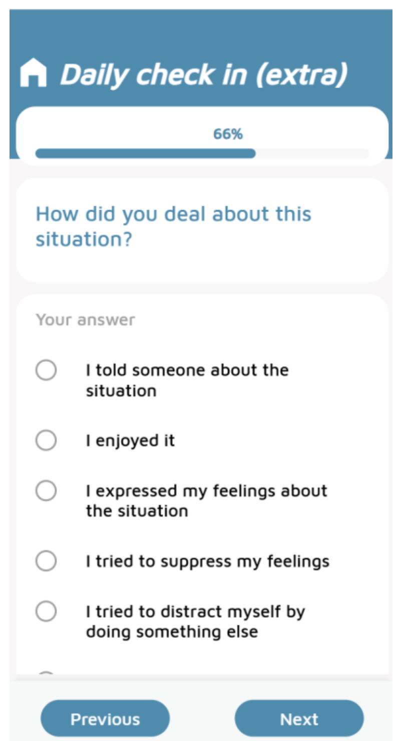

Daily check in (extra)
47%
Think about the most PLEASANT situation since the last survey. This was a ....
Your answer
pleasant event
pleasant thought
pleasant emotion
pleasant bodily sensation
There was no pleasant situation
Previous
Next

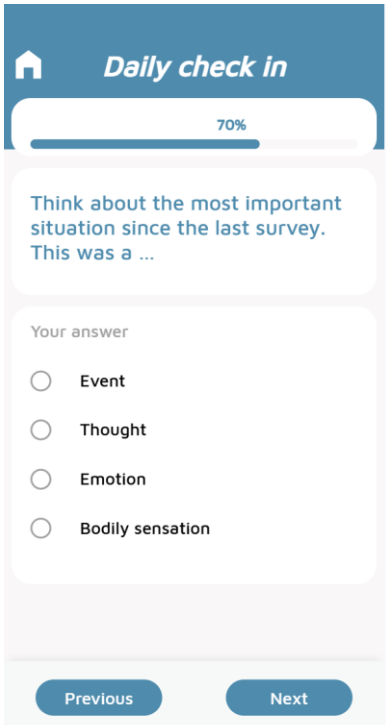

Daily check in (extra)
50%
Briefly describe this situation
Your answer
Type in your answer...
0/500
Previous
Next

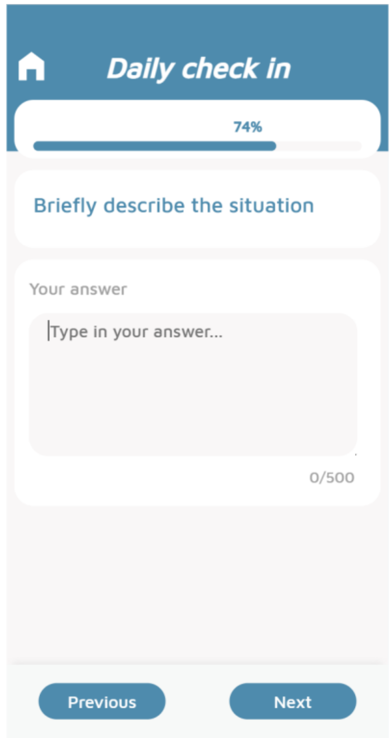

Daily check in (extra)
54%
How pleasant was this situation?
Your answer
0
not pleasant at all
very pleasant
Previous
Next

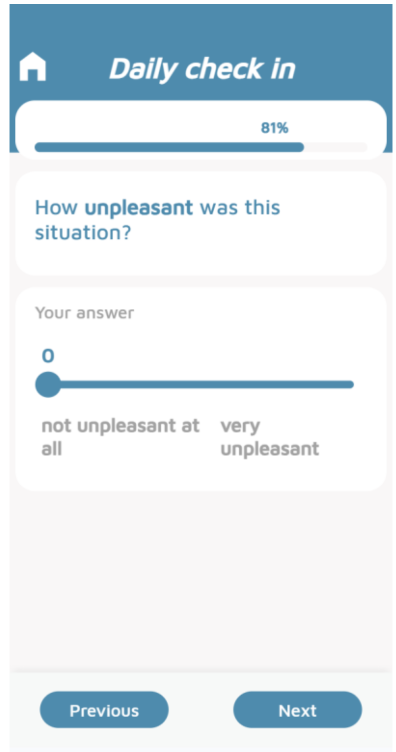

Daily check in (extra)
58%
How stressful was this situation?
Your answer
0
not stressful at all
very stressful
Previous
Next

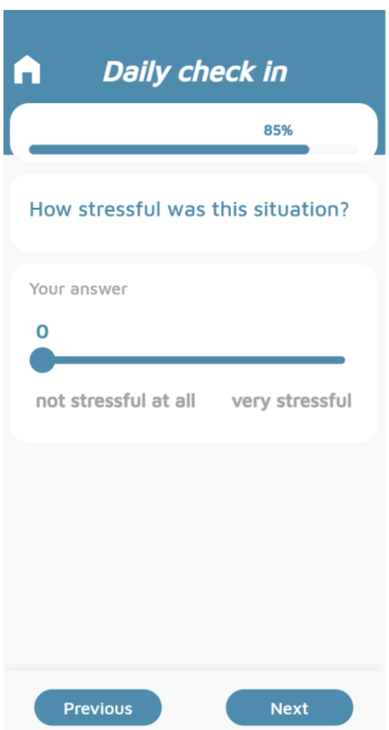

Daily check in (extra)
62%
How have you thought about this situation?
How did you look back at the situation?
In what way were you thinking about the situation afterwards?
Your answer
I thought back on it positively
I thought back on it negatively
I tried not to think about it
I haven't thought about it
Previous
Next

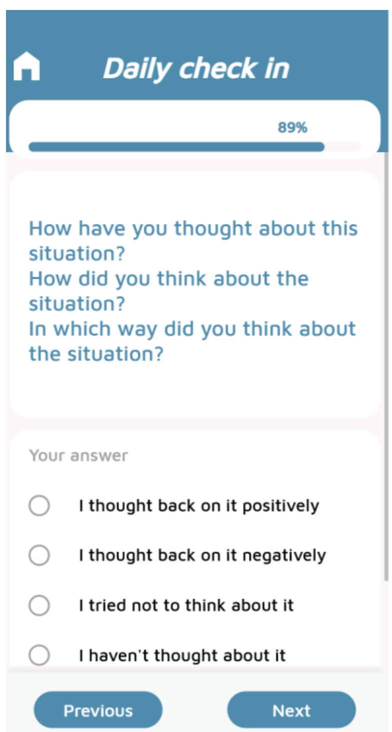

Daily check in (extra)
66%
How did you deal about this situation?
Your answer
I told someone about the situation
I enjoyed it
I expressed my feelings about the situation
I tried to suppress my feelings
I tried to distract myself by doing something else
Previous
Next

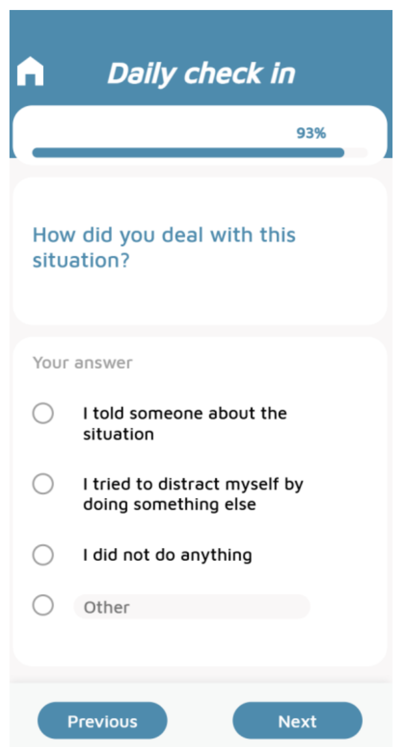

Daily check in
70%
Think about the most important situation since the last survey. This was a ...
Your answer
Event
Thought
Emotion
Bodily sensation
Previous
Next


Daily check in
74%
Briefly describe the situation
Your answer
Type in your answer...
0/500
Previous
Next

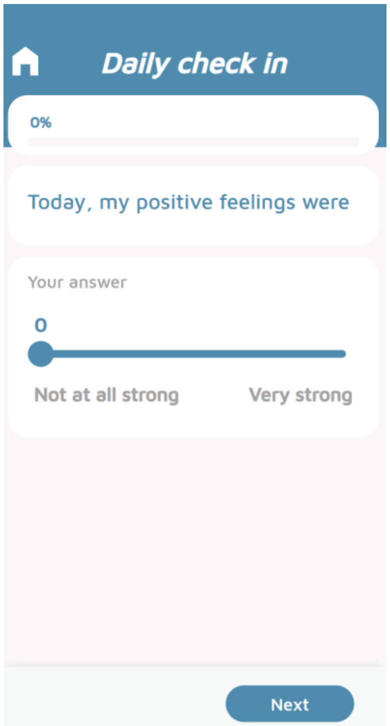

Daily check in
81%
How unpleasant was this situation?
Your answer
0
not unpleasant at all
very unpleasant
Previous
Next

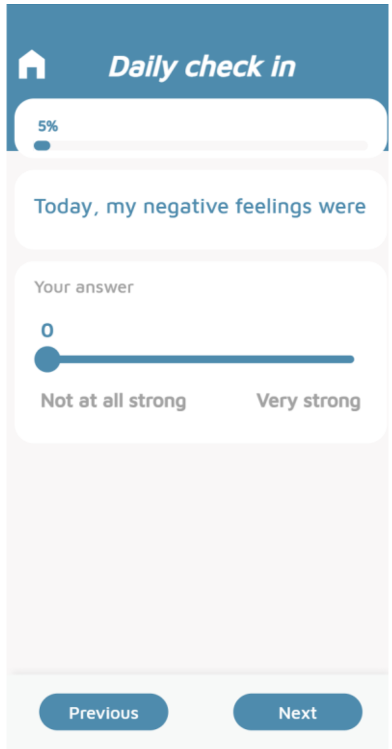

Daily check in
85%
How stressful was this situation?
Your answer
0
not stressful at all
very stressful
Previous
Next

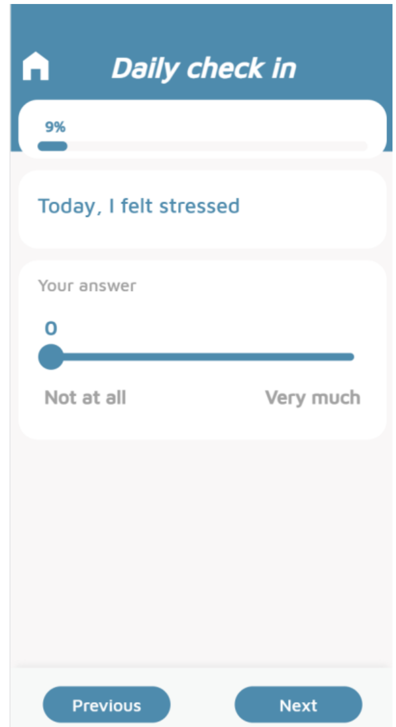

Daily check in
89%
How have you thought about this situation?
How did you think about the situation?
In which way did you think about the situation?
Your answer
I thought back on it positively
I thought back on it negatively
I tried not to think about it
I haven't thought about it
Previous
Next

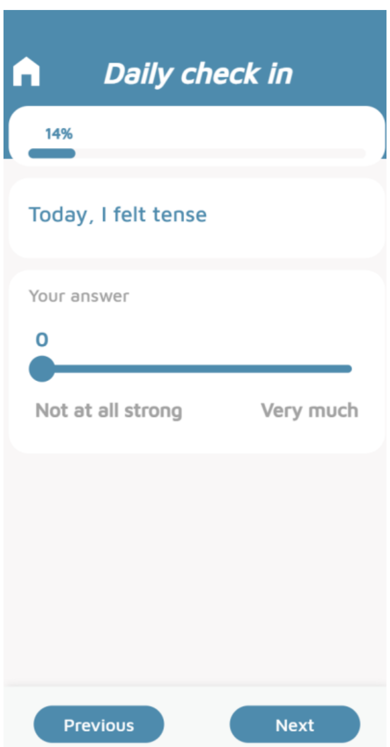

Daily check in
93%
How did you deal with this situation?
Your answer
I told someone about the situation
I tried to distract myself by doing something else
I did not do anything
Other
Previous
Next

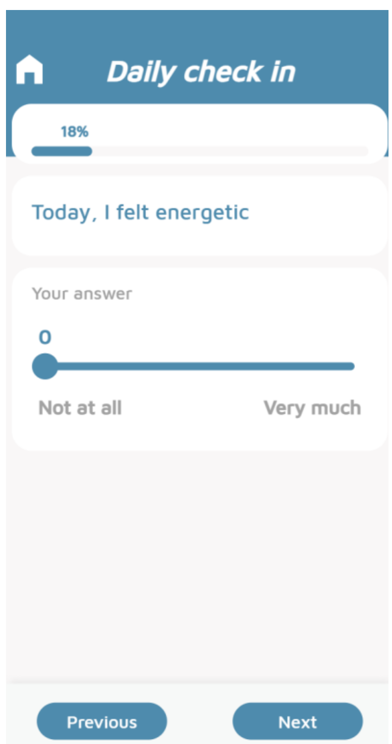
Appendix H - Core Questionnaire Evening

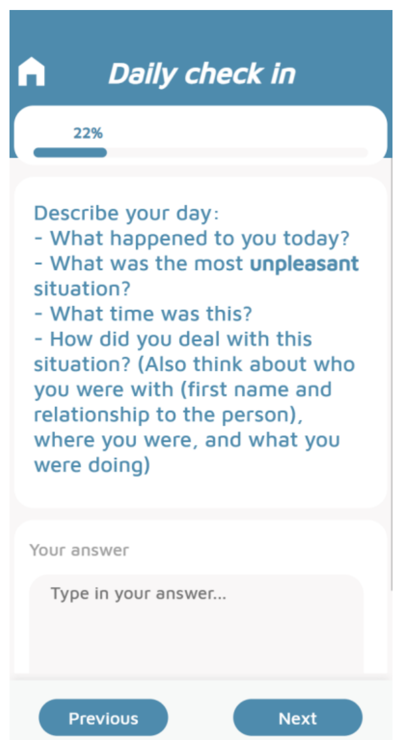


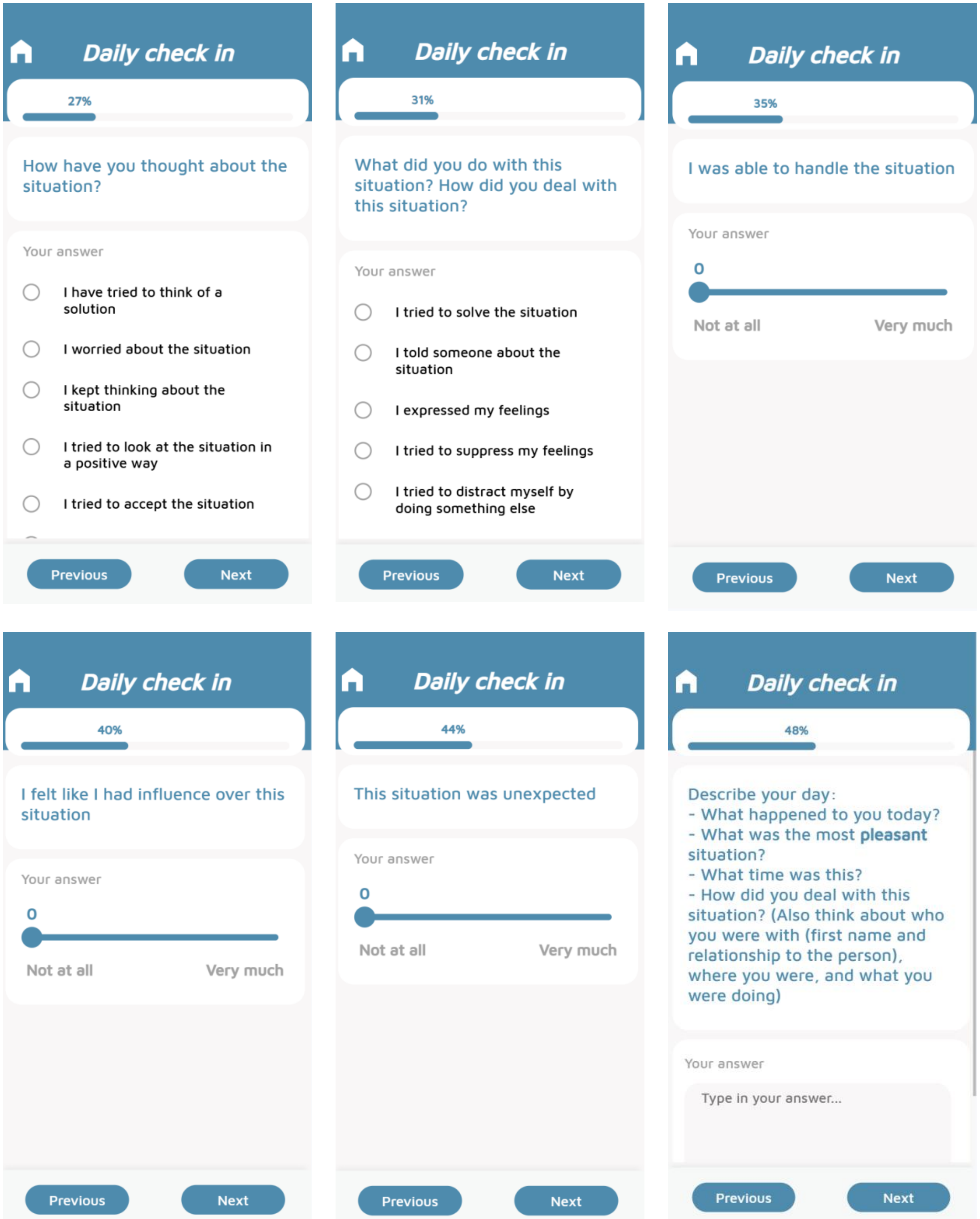


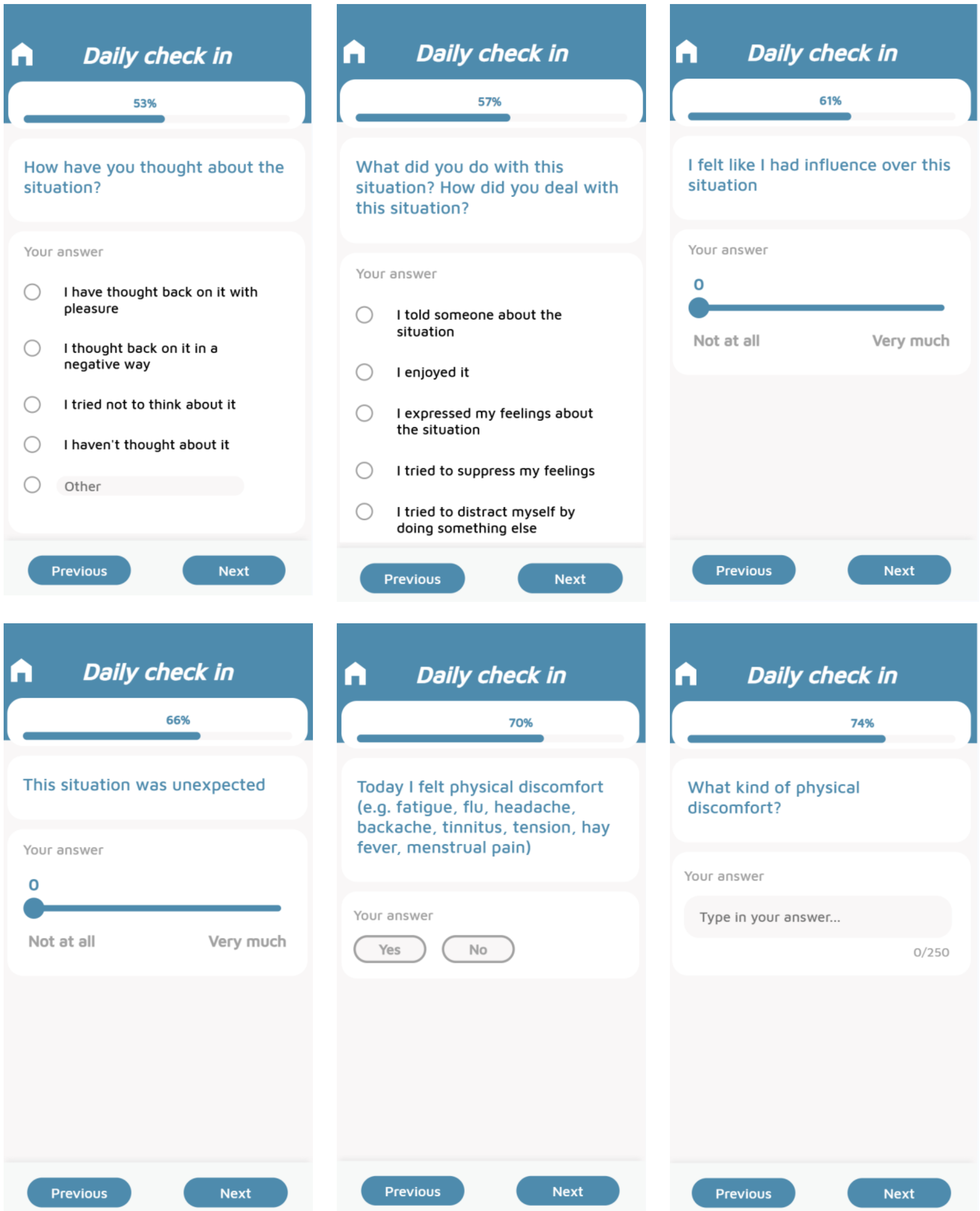


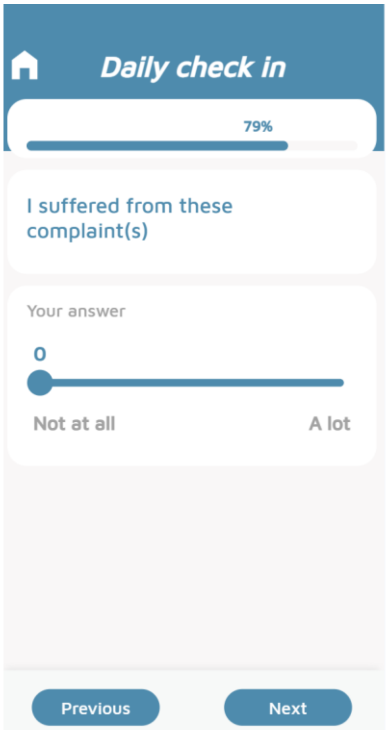


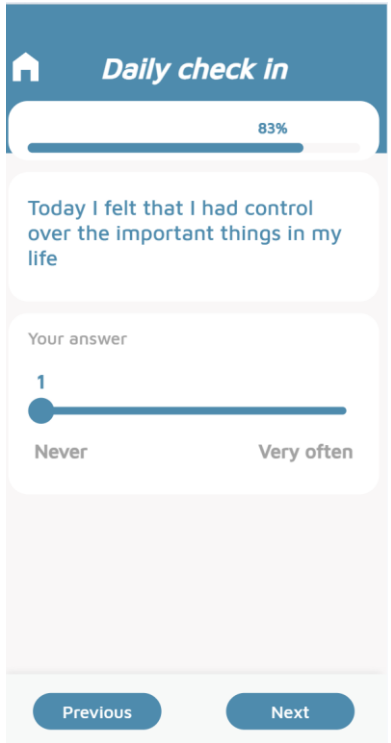


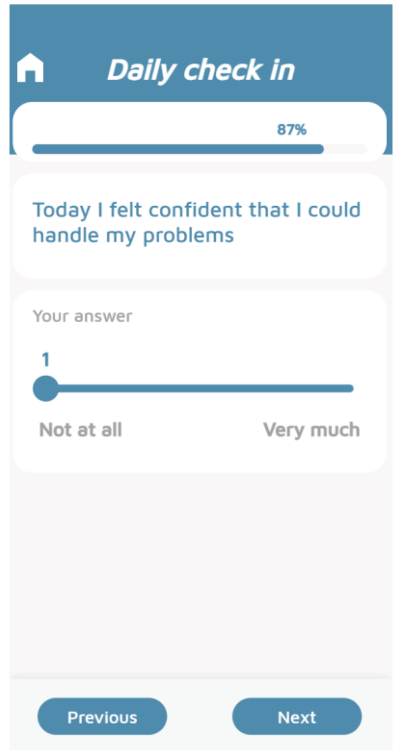


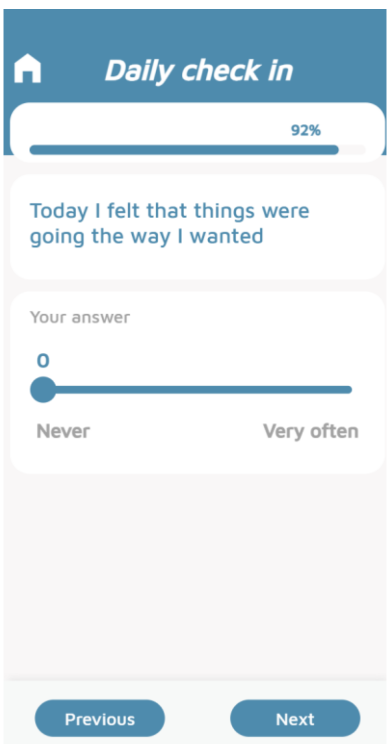

Daily check in
27%
How have you thought about the situation?
Your answer
I have tried to think of a solution
I worried about the situation
I kept thinking about the situation
I tried to look at the situation in a positive way
I tried to accept the situation
Previous
Next
Daily check in
31%
What did you do with this situation? How did you deal with this situation?
Your answer
I tried to solve the situation
I told someone about the situation
I expressed my feelings
I tried to suppress my feelings
I tried to distract myself by doing something else
Previous
Next
Daily check in
35%
I was able to handle the situation
Your answer
0
Not at all
Very much
Previous
Next
Daily check in
40%
I felt like I had influence over this situation
Your answer
0
Not at all
Very much
Previous
Next
Daily check in
44%
This situation was unexpected
Your answer
0
Not at all
Very much
Previous
Next
Daily check in
48%
Describe your day:
- What happened to you today?
- What was the most pleasant situation?
- What time was this?
- How did you deal with this situation? (Also think about who you were with (first name and relationship to the person), where you were, and what you were doing)
Your answer
Type in your answer...
Previous
Next

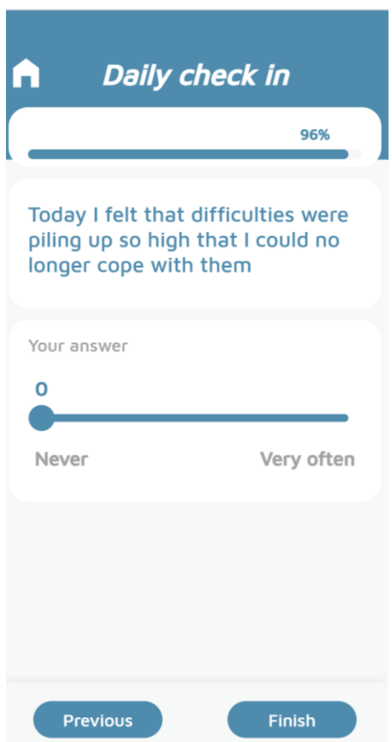

Daily check in
53%
How have you thought about the situation?
Your answer
I have thought back on it with pleasure
I thought back on it in a negative way
I tried not to think about it
I haven't thought about it
Other
Previous
Next
Daily check in
57%
What did you do with this situation? How did you deal with this situation?
Your answer
I told someone about the situation
I enjoyed it
I expressed my feelings about the situation
I tried to suppress my feelings
I tried to distract myself by doing something else
Previous
Next
Daily check in
61%
I felt like I had influence over this situation
Your answer
0
Not at all
Very much
Previous
Next
Daily check in
66%
This situation was unexpected
Your answer
0
Not at all
Very much
Previous
Next
Daily check in
70%
Today I felt physical discomfort (e.g. fatigue, flu, headache, backache, tinnitus, tension, hay fever, menstrual pain)
Your answer
Yes
No
Previous
Next
Daily check in
74%
What kind of physical discomfort?
Your answer
Type in your answer...
0/250
Previous
Next


Daily check in
79%
I suffered from these complaint(s)
Your answer
0
Not at all
A lot
Previous
Next

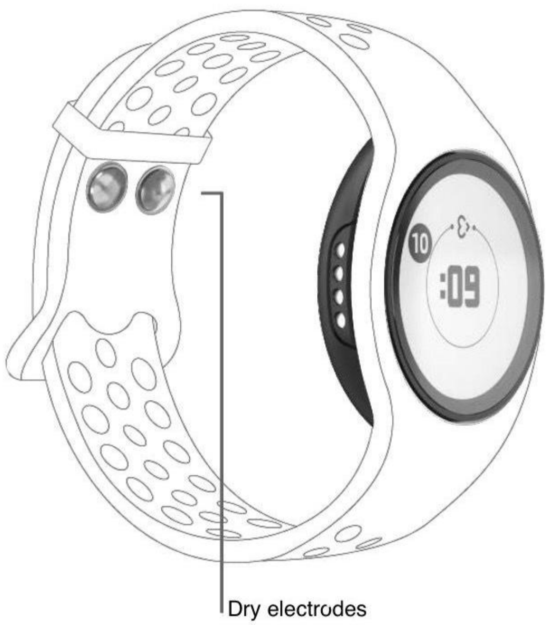

Daily check in
83%
Today I felt that I had control over the important things in my life
Your answer
1
Never
Very often
Previous
Next

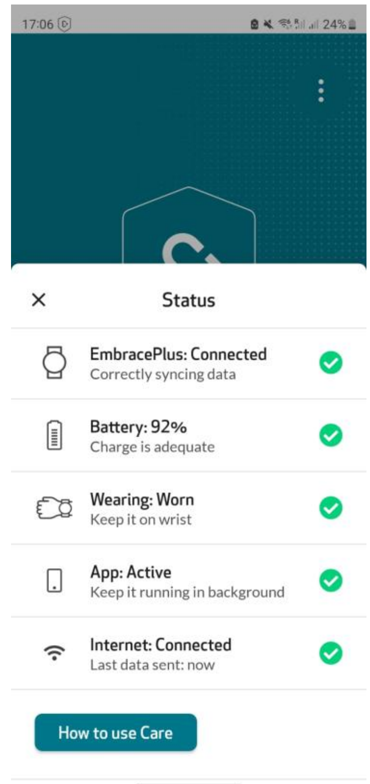

Daily check in
87%
Today I felt confident that I could handle my problems
Your answer
1
Not at all
Very much
Previous
Next


Daily check in
92%
Today I felt that things were going the way I wanted
Your answer
0
Never
Very often
Previous
Next


Daily check in
96%
Today I felt that difficulties were piling up so high that I could no longer cope with them
Your answer
0
Never
Very often
Previous
Finish

Appendix I - Embrace Plus, Care Lab Portal, and Care Lab App





Appendix J - Coping Strategies and Categorisation

	Rest and Relaxation Strategies Count	Cognitive Reframing and Rationalisation Count	Stress Eating Count	Social Coping Count	Problem-focused Coping Count
Always try and relax and do a thing to get it out of my mind (for example: exercise, play games, watch a series)	✓				
Back off, get in rest, eat/drink something sweet			✓		
Be calmer during times of stress and get it done one by one					✓
Be more prepared and stay calm					✓
Breathe, think clearly, arrange my thoughts better.	✓				
By walking out and by chatting with real friends				✓	
Do something relaxing and some leisure activities. Less on assignments and tasks	✓				
go home and take some rest	✓				
Have a break time in 5 minutes, taking breath	✓				
I don't feel too stressful after the experiment, but will wind down as it' s the end of the day anyway and the source of my other stress (my work) is over too.				✓	
I feel more comfortable speaking to people in real life so I won't be stressed in the first phase. And for the second, I will bring a piece of paper and pen to count!					✓
I know its fake so im not stressed		✓			
I think I need to eat good food especially sweat food because I the task is quite hard for me			✓		
I will eat and watch funny videos			✓		
I will share my experience with my friend and express my feelings about it.				✓	
I will take a deep breath and try me best to prepare the situation before it's happened in advance.					✓
I will take some time on my own for myself to recollect and calm myself down.	✓				
I will tell myself it was just an experiment and it was already done, I don't need to worry about it anymore		✓			
Let it be	✓				
Let myself know being aware that VR is fake and I'm in a safe environment! I'm not dealing with the stress in real life so I can calm down!		✓			
Maybe I should also treat it lighter				✓	
Not seeing screen	✓				
Probably the same as before, which is pretending its not there		✓			
Reducing mentally intensive tasks	✓				
Relax, breathe, take a walk, focus on pleasant thoughts, and in general feeling out of the situation is already relaxing to me.	✓				
Rest	✓				
Sit and doing nothing	✓				
Sleep and eat good food			✓		
Stay calm and focus		✓			
Take some fresh air.	✓				
Take some rest, life must go on	✓				
Try to relax and watch some videos online.	✓				