

**Exploring the Relationship Between Sedentary Behaviour and Perceived Stress in
Students with Rumination as a Moderator, using Experience Sampling Methods**

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Abstract

Purpose: Sedentary behaviour (SB) can have negative effects on mental health, but not a lot of research has been performed on the relationship between SB, rumination and perceived stress. Students spend significantly more time in SB than non-students and as a result are at risk of possibly experiencing more perceived stress than others, exacerbated by rumination. Thus, this study investigates whether sedentary behaviour is associated with perceived stress and whether rumination moderates this relationship over time.

Methods: This study used an experience sampling method design in a student sample ($N = 25$). At the start of the study, participants' rumination levels were measured. Then, over the course of 15 consecutive days, students were measured on their total sedentary time and perceived stress levels. Measurements were taken through the mobile application m-Path and linear mixed models were used for analysing the hierarchical and long-form data.

Results: No significant relationship was found between the variables sedentary behaviour and perceived stress ($b = 0.03$, 95% CI = [-0.01, 0.07]). Additionally, rumination was found to not moderate the relationship between sedentary behaviour and perceived stress ($b = -0.001$, 95% CI = [-0.01, 0.01]). A weak relationship was found between rumination and perceived stress ($b = 0.13$, CI = [0.03, 0.24]).

Conclusion: There does not seem to be a significant relationship between sedentary behaviour and perceived stress levels in students, regardless of trait rumination levels. Factors surrounding SB such as context may have more weight on this relationship than just SB by itself. This can be considered a positive finding for students, as they spend a lot of their time in SB. The study adds onto previous literature and proposes future study recommendations.

Keywords: sedentary behaviour, rumination, perceived stress, experience sampling methods

Introduction

In recent decades, the way people spend both their spare and occupational time has changed significantly and people spend more time sitting or lying down during leisure or work activities. These behaviours, also known as sedentary behaviours (SB), have become increasingly more common in day-to-day life. As defined by Tremblay et al. (2017) and the Sedentary Behaviour Research Network (2019), sedentary behaviour is “any waking behaviour characterised by an energy expenditure ≤ 1.5 metabolic equivalents while in a sitting or reclining posture” (p. 5). Some of the more common SBs are commuting, sitting at school or work, or screen-related activities (Owen et al., 2000; Park et al., 2020). The amount of time someone spends in SBs is known as sedentary time (ST), and this term is often used when measuring SB. Students are reported to have a higher average of sedentary time than non-students of the same age. As reported by Castro et al. (2020), students spent an average of 7.29 hours a day sitting, whilst non-students of the same age only spent 5.86 hours a day performing SB. This is also almost more than 2 hours more than the suggested threshold of 5.6 hours (Borojevic, 2016). Thus, on average, students spend a lot more time in SB than non-students.

Spending long periods of time in SB can have negative effects on physical and mental health. Borojevic (2016) noted that after sitting for more than 5.6 hours, mental well-being tended to decrease, whilst psychological distress increased. Findings by Gibson et al. (2017) and Castro et al. (2020) support this, as they found that spending over 8 hours a day in sedentary behaviours is associated with worse perceived mental health and poorer quality of life. Furthermore, high amounts of sedentary behaviour has been associated with a higher risk of all-cause cardiovascular disease, cancer mortality, (type 2) diabetes and worse cognitive function (Gilchrist et al., 2020; Patterson et al., 2018; Saunders et al., 2020). It is important to note that these negative outcomes are regardless of levels of physical activity (Biswas et al.,

2015; Gibson et al., 2017). All of these findings highlight the profound impact that sedentary behaviour can have on a person and the possible risks students face as a result of their SB.

Sedentary behaviour is associated with various mental health outcomes. For example, prolonged time spent sedentary can have a negative effect on mood and is associated with an increased risk of depression (Ellingson et al., 2018; Zhai et al., 2015). One less investigated variable is stress and how SB is associated with the experience of stress. Teychenne et al. (2019) proposed that sedentary behaviour may be associated with perceived feelings of stress as engaging in SB can displace time spent on other important activities such as work (study)-related responsibilities, exercising, or household activities. Furthermore, sedentary behaviours could be associated with state levels of stress through both direct and indirect effects. To illustrate, screen-based sedentary behaviours can induce sleeping problems, ‘brain burnout’ and feelings of addiction that might consequently lead to an increased sense of psychological stress (Teychenne et al., 2019). Thus, SB can possibly be associated with stress and this relationship requires further investigation.

Stress is a term used in all settings of life and has been found to have many negative effects on individuals, and yet it has not been studied often in relation to SB. For students, they often face many challenges in their day-to-day activities which can lead to stress (Varghese et al., 2015). As described by Cohen et al. (2007), psychological stress happens when an environmental demand or mental tax exceeds an individual’s adaptive capacity. Chronic stress is considered to be the most damaging, as it results in long-term or even permanent changes in emotional, physiological, and behavioural responses that influence disease susceptibility (Cohen et al., 2007). These findings are supported by Gustems-Carnicer et al. (2019) who noted that prolonged experience of stress can influence adaptive functioning, increasing the occurrence of risk behaviours such as addiction, excessive alcohol use, and eating disorders. Therefore, stress can have various negative effects on physical and mental well-being and

investigating whether or not SB is associated with stress is important for both students and other individuals.

Various factors can prolong the experience of stress. One of these factors is rumination (Watkins & Roberts, 2020). Rumination is a behaviour where someone continuously engages in repetitive thinking about negative past-related content and these events are often based around one's self, feelings, personal concerns, or upsetting experiences (Lu et al., 2024; Watkins et al., 2008; Watkins & Roberts, 2020). As a result, they are often unable to move past those thoughts and remain stressed as a result. Watkins & Roberts (2020)'s research notes how rumination can act as a common pathway for distal risk factors for emotional disorders. To name a few, rumination exacerbates existing psychopathology, impairs concentration and sensitivity to context, and can act as a transdiagnostic mental health vulnerability (Watkins & Roberts, 2020). Additionally, rumination can lead to prolonged activation of the stress system and for those who ruminate often these sustained and elevated levels of cortisol can have various health consequences (Zoccola & Dickerson, 2012). Considering that stress has been found to be a risk factor for mental health problems, rumination could possibly exacerbate this relationship further and thus this relationship must be investigated further.

The relationship between sedentary behaviour and rumination is often negative. A recent study by Lu et al. (2024) suggested a possible explanation for their concept of repetitive negative thinking (RNT) is that longer (uninterrupted) sitting time may be associated with reduced cerebral blood flow which may lead to poorer cognitive functions, thereby increasing ruminative thinking. Most of the other studies look at rumination in the context of depression however, and not in the context of stress as is the interest of this study (Constantin et al., 2018; Lu et al., 2024; Shaw et al., 2023). Thus, it seems that there is a negative relationship between SB and rumination, but the moderating effect of rumination on the relationship between SB and stress has yet to be investigated.

There seems to be a relatively little amount of studies that examine the moderating effect of trait rumination on state perceived stress in the context of sedentary behaviour. One study investigated how the interaction between ruminative response styles and stress would predict changes in psychological distress. They found that stress was associated with insomnia and anxiety, but also an interaction was found between stress and rumination (Morrison & O'Connor, 2005). Additionally, they propose that avoidant thinking leads to increased rumination. Based on these findings, it could be that trait rumination levels are associated with the extent someone feels perceived stress as a result of SB. To conclude, although there is some indication that stress, rumination, and sedentary behaviour are linked, there is not a lot of current research examining the degree to which trait rumination can influence the degree of stress as a result of SB.

The relationship between sedentary time, stress, and rumination can be investigated using the Experience Sampling Methodology (ESM). As noted by Myin-Germeys et al. (2018), ESM is used to investigate experiences and uses a structured self-report diary technique where participants often complete multiple momentary questionnaires per day over a number of days in order to gather data. The technique allows for the assessment of symptoms, context, and appraisals as they occur in daily life (Myin-Germeys et al., 2018). Considering the extent of SB can differ between days, as well as state levels of perceived stress, using ESM allows the observation of variations for both within and between individuals (Dogan et al., 2022; Maher et al., 2021; Moberly & Watkins, 2008; Myin-Germeys et al., 2018).

The current study aims to investigate whether individuals with higher levels of trait rumination also experience higher levels of perceived stress as a result of SB than those with lower levels of trait rumination. This allows for a more comprehensive understanding of the relationship between sedentary behaviour and stress, and how rumination can affect it during

the daily life of students. Therefore, the paper attempts to answer the following research questions:

1. What is the relationship between sedentary time and perceived stress in students over time?
2. Is the relationship between sedentary time and perceived stress in students moderated by rumination over time?
3. Is the relationship between sedentary time and perceived stress more a relationship between-subjects or within-subjects over time?

It was expected that higher sedentary time is positively associated with a higher amount of perceived stress. Additionally, it was expected that this relationship is increased by trait rumination, meaning that the effect of sedentary behaviour on perceived stress is higher in individuals who also reported higher levels of trait rumination. Thus, those who are more prone to ruminate are more likely to experience higher degrees of perceived stress. These expectations were made on the basis of previous findings on the related subjects as discussed in the introduction.

Methods

Study Design

This longitudinal ESM study was conducted in collaboration with four other Bachelor's degree students. Each of these students worked on related topics, but each with their own distinct research questions. Because of this, during data collection the experience sampling study included several questionnaires, each related to the specific aspects of their research. Only those relevant to this study will be explained below. The ESM data was collected via the platform m-Path, a free tool developed by KU Leuven. It is often used for ESM studies as it allows for short momentary surveys. These short momentary surveys help to facilitate the monitoring of state perceived stress and other aspects of the study. The study was approved by the Ethics Committee of the University of Twente on the 20th of March, 2024 (request 240234). The study used a time-contingent form of ESM, which means that the data was collected three times a day over various, fixed timeframes. Data collection took place between 8th of April and the 23rd of April.

In order to ensure participant response rate and to prevent a high participant burden, the study was conducted over a duration of 16 days. The duration of the data collection was deemed appropriate based on findings of a meta-analysis of van Berkel et al. (2017), who highlighted that the median study duration of 14 days was an accurate representation of other ESM studies and recommended a minimum duration of 7 days. They also noted that this, along with requesting multiple short questionnaires per day, usually resulted in a good response rate. It is estimated that after 2 to 4 weeks of data collection, the quality of data reporting declined (Scollon et al. 2003). Additionally, Dogan et al.'s (2022) meta-analysis showed that most studies measuring stress using ESM had a duration between 8 and 14 days. Based on this information, it was decided that this study will have a duration of 16 days.

Participants

The aim of this study was to recruit at least 20 participants. Van Berkel et al. (2017)'s literature review noted a median number of 19 participants and thus recruiting at least 20 participants seems reasonable. Participants had to meet six inclusion criteria in order to be allowed to participate. Participants had to be over 18 years old, proficient in English, and had to be enrolled in university or other higher education (f.e. the Dutch HBO or German Fachhochschule). Participants were required to have access to either an Android or Apple mobile phone for the duration of the study and had to be willing to download the required application for the study. Additionally, participants had to be able to stand for more than 30 minutes at a time and were not bound to a wheelchair. Finally, participants had to have given informed consent before they could start the study (see Appendix A). Participants were recruited through non-probability sampling. Researchers used convenience sampling by contacting people that fit the criteria personally (through Whatsapp, Instagram, and Discord), but also voluntary response sampling as the study was accessible via the SONA programme, where University of Twente students can get credits for participating in studies. Students participating in the study could acquire 3 SONA points for participating in the study.

At the start of the study, 47 participants took part in the study. After the completion of the study, 6 participants were removed from the dataset due to them not filling in the informed consent form at the start of the study and 16 participants were removed after the study due to low response rate (< 50%) (Connor & Lehman, 2012; Kang, 2013). Excluding these removals, a total of 25 participants were considered for data analysis. This is more than the median of 19 noted by van Berkel et al. (2017). Participants ranged from 18 to 29 years old, with a mean age of 21.68 ($SD_{age} = 2.61$). All participants were students, with a division of 24 university students (96%) and 1 other higher education students (4%). The sample consisted of 14 males (56%)

and 11 females (44%). Finally, in terms of nationality, 7 of the participants were Dutch (28%), 14 were German (56%), and 4 were from other nationalities (16%).

Procedure

Once participants signed up for the study they were directed to download the m-Path app for either Android or iOS mobile devices. In order to be able to participate in the study, they were instructed to fill in a nickname and then link themselves with the practitioner code provided by the researchers. Participants were not required to link an email address. Once they had completed this, the researchers could schedule the respective surveys.

On the first day and first data collection point (8th of April), participants were informed about the purpose of the research and were asked to give informed consent. Following this, some demographic questions were given and questions were asked in order to measure participant trait rumination. These questions were not repeated the following 14 days. The following 14 days, participants were measured three times a day. Sedentary time was only measured in the morning and asked about the total amount of time spent in SB the day before the moment of measurement. This was done because this study looks at total ST and answering at the end of the day itself could lead to lower ST than if asked the day after, as participants might still perform SB after answering that day. For an overview of the survey schedule and the measured variables per moment, see Table 1.

Participants would receive a notification which notified them that their questionnaire was available and were asked to fill it in. After 60 minutes a reminder was sent and once 120 minutes had passed, the survey expired and could no longer be completed. This was done in order to have an as accurate state measure as possible and to ensure they would not overlap. If a participant failed to fill in a survey, the survey moment would be handled as missing data. Future notifications would continue like normal.

Table 1*Schedule overview of the study period*

	April 8th	April 9th	April 10th - 22nd	April 23rd
10.00 - 22.00	Demographics & Trait Rumination			Sedentary behaviour
10.00 - 12.00		State perceived stress	Sedentary behaviour + State perceived stress	
15.00 - 17.00		State perceived stress	State perceived stress	
20.00 - 22.00		State perceived stress	State perceived stress	

Materials

Below the used items for the baseline and repeated measurements will be described.

For a full overview of the exact questions, view appendix B.

Baseline measurement

Demographics. The baseline questionnaire used a few short demographic questions in order to better establish the sample characteristics. Four items were used to gather demographic data. Participants were asked about their age, gender, nationality, and current occupation. For age, participants were asked to fill in their age with a number. For gender, four options were given: ‘Male’, ‘Female’, ‘Other’, and ‘Prefer not to say’. There were three options for nationality, which were ‘Dutch’, ‘German’, and ‘Other’. Finally, there were three options for current occupation: ‘Enrolled at a university’, ‘Enrolled at another higher education institution (HBO, Fachhochschule)’, and ‘Other’. If a participant selected the option ‘Other’, they would be excluded from the study as the target group for this study are higher education students.

Trait rumination. Trait rumination was measured with the Ruminative Response Scale Short Form (RRS-SF) (Treynor et al., 2003). The RRS-SF consists of 10 items on a 4-point Likert scale ranging from ‘almost never’ (1) to ‘almost always’ (4). Example items of the

RRS-SF are: “How often do you think ‘Why do I have problems others don’t have?’” and “How often do you write down what you are thinking and analyse it?”. The original Ruminative Response Scale (RRS) has had a critique of being too focused on depression, which the short form corrects (Treyner et al., 2003). Sufficient construct validity was found for the overall scale based on factor loadings of the items (Erdur-Baker & Bugay, 2010; Thanoi & Klainin-Yobas, 2015). Additionally, Thanoi & Klainin-Yobas (2015) demonstrated that the scale had a good internal consistency reliability overall, with a value of .80. In this study, the total scale of the RRS-SF had a good Cronbach’s alpha of .72

Repeated measurements

Due to the nature of experience sampling methodology, it is important to keep the state measures as brief as possible while still gathering the desired information on the investigated variables (Myin-Germeys et al., 2018). In order to accomplish this, items used in the study were derived from validated questionnaires. For an overview of measurement instruments, see Table 2.

Table 2

Overview of measurement instruments used for the items of this study

Measure variable	Demographic data	Trait rumination	Total sedentary time	State perceived stress
Item amount	4	10	7	1
Created, derived, reformulated or combined	Created	Derived from the RRS-SF	Derived, reformulated, and combined from the PAST-U	Derived from the SNSR-11

Note. PAST-U = Past-day Adults’ Sedentary Time-University. SNSR-11 = Stress Numerical Rating Scale-11. RRS-SF = Rumination Response Scale Short Form.

Sedentary Time. To measure sedentary time, a modified Past-day Adults' Sedentary Time-University (PAST-U) test was used. The original PAST-U consists of 9 items which describe different contexts in which sedentary behaviour could take place (Clark et al., 2016). Respondents are asked to fill in the amount of time spent in SB for each context in hours and minutes for the previous day. The PAST-U has an adequate content validity of .63, and an adequate reliability, with an intraclass correlation (ICC) of .64 (Clark et al., 2016; Prince et al., 2017). In this study, the PAST-U had a split-half reliability of .56.

In order to better suit the ESM design, four items were combined into two merged items. Additionally, all the items were shortened and slightly reformulated to better fit the ESM study design. Item 1 and item 2 were merged as they described time spent during work and study, and in this study these were considered to be of similar context. Combined, they formed the item: "How long were you sitting while studying/working yesterday? (Include the time at university, during lectures, tutorials, meetings, group discussions, study/work from home, etc.)". Secondly, item 4 and item 5 were merged as TV and computers are now both used interchangeably in day to day life. The item that resulted from this merge was: "How long were you sitting or lying down while watching TV, internet-use or playing video games yesterday? (Include activities that were not for studying/working purposes, like social media, online shopping, etc.)". In total this study uses the sum of 7 items to measure total daily sedentary time.

Perceived Stress. In order to measure the state perceived stress, the Stress Numerical Rating Scale-11 (SNRS-11) was used (Karvounides et al., 2016). The SNRS-11 only has one question and aims to measure momentary perceived stress. The singular item which will be used is the following: "On a scale of 0 to 10, with 0 being 'no stress' and 10 being 'worst stress possible', what number best describes your level of stress right now?" (Karvounides et al., 2016). The SNRS-11 was found to have a significant and moderate construct validity of .31

when compared to the Perceived Stress Scale (PSS), another often-used measure for measuring perceived stress. Additionally, SRNS-11 scores were found to correlate strongly with the STAI-C, the study's primary measure of construct validity, with a construct validity of .60 (Karvounides et al., 2016). In this study, the SNRS-11 was found to have a split-half reliability of .94.

Data Analysis

After data collection had concluded, participant data was exported to an Excel format. In Excel, data was organised to allow it to be imported into the 29th version of SPSS. In order to analyse trait rumination and total sedentary time, their items were summed up. In some cases sedentary time exceeded 18 hours. As sleep is excluded from this study and over 18 hours of ST seems implausible, the total ST was capped at 18 hours.

After the preparation and cleaning of the dataset, descriptive statistics were gathered on both the demographical data and the variables under study. For every variable the means and standard deviations were calculated. In order to investigate the internal consistency reliability of the RRS-SF, Cronbach's alpha was calculated. Based on the review by Taber (2018), an alpha of .70 or above was considered as good reliability. Additionally, split-half analyses were performed to investigate reliability for both the PAST-U and SNRS-11 in this study. The measurements were split into two halves (timepoint 1-21 and 22-43), which were summed up and analysed in order to gather Spearman-Brown coefficients.

The repeated variables were analysed using Linear Mixed Models (LMM). Due to the long-form nature of ESM data, regular linear models are not applicable as they can not handle multiple time points per participant (Stadler et al, 2017). Next to that, LMM can account for missing data and allows for the calculation of estimated marginal means for variables. Finally, the LMM were performed using first-order auto regressive covariance (AR1). AR1 considers

that observations that are close together in time correlate stronger than observations that are further away in time from each other.

In order to examine the research questions, various LMM analyses were performed. In each of these, participants were set as the subjects and the points of measurement were chosen for the repeated measure. For the first research question the independent variable (IV) was sedentary time and perceived stress the dependent variable (DV). For the second research question, the examined variables were perceived stress (DV), sedentary time (IV), trait rumination (moderator variable), and the interaction effect between sedentary time and trait rumination (IV). Then, estimated marginal means (EMMs) for ST and perceived stress were calculated and qualitatively analysed across participants and timepoints through Excel. To explore the relationships further, data of 5 participants were visualised through Excel and qualitatively analysed. These participants were chosen due to high response rate, high trait rumination and low trait rumination levels.

Then, in order to gain some more detailed information on the dataset and to answer the third research question, both between-person and within-person analyses were investigated (Curran & Bauer, 2011). First, personal means (PM) of sedentary time were calculated through de-aggregation. Then, the PMs were subtracted from the total ST values to calculate the personal mean centred (PMC). LMM were used to explore the relationship between perceived stress (DV) and the PMC and PM of sedentary time (IV).

Results

Descriptive results

The descriptive statistics of the variables under study were examined in order to place the findings into context ($N = 25$; see table 3). The average response rate was 79.8% and the total amount of observations in this sample was 878 out of 1100. Mean state perceived stress was 2.21 ($SD = 2.28$). This was on the lower end of the scale, as values can range from 0 to 11. Trait rumination had a mean of 20.92 ($SD = 4.40$), meaning it was on the lower end of the scale as answers could range from 10 to 40. The respective standard deviations were relatively low, suggesting that these variables did not vary greatly within the sample. The mean for total sedentary time was high with 10 hours and 38 minutes ($SD = 4.70$). The high standard deviation suggests that total sedentary time varied greatly within the sample. Viewing the descriptive statistics, the sample was characterised by low means in trait rumination and state perceived stress, but with high mean levels of sedentary behaviour.

Table 3

Minimum & Maximum (Range), Mean, and Standard Deviation for the studied variables

	Minimum	Maximum	Mean	Std. Deviation
Sedentary Time in hours	0.20	18	10.63	4.70
Trait Rumination	15	30	20.92	4.40
Perceived Stress	0	10	2.21	2.28

RQ 1 & 2: Relationship between Total ST, Rumination and State Perceived Stress

Unlike the expectations for RQ 1, the linear mixed model analysis showed no significant relationship ($b = 0.03$, $CI = [-0.01, 0.07]$) between sedentary time and perceived stress (see table 4). Furthermore, in contrary to the expectations of RQ 2, there was no

significant main relationship of sedentary time on perceived stress with trait rumination as a moderator ($b = 0.04$, $CI = [-0.13, 0.22]$). However, a weak but significant relationship was found between trait rumination and perceived stress ($b = 0.13$, $CI = [0.03, 0.24]$). Finally, there was no significant interaction effect and relationship between sedentary time, trait rumination, and perceived stress ($p = .84$) (see table 4).

Table 4

Summary of general results of analyses

Analysis	Independent variable(s)	<i>F</i>	Estimate (<i>b</i>)	<i>SE</i>	<i>t</i>	<i>Sig.</i>	95% Confidence Intervals	
							Lower bound	Upper bound
RQ 1	Sedentary Time	2.45	0.03	0.02	1.56	.11	-0.01	0.07
RQ 2	Sedentary Time	0.21	0.04	0.09	0.46	.64	-0.13	0.22
	Trait Rumination	6.41	0.13	0.05	2.53	.01*	0.03	0.24
	Sedentary Time*Trait Rumination	0.39	-0.001	0.004	-0.19	.84	-0.01	0.01

Note. * indicates $p < .05$. Dependent variable in all analyses = perceived stress.

Estimated Marginal Means

Based on the visualisation in Figure 1, it seems that the participants are characterised by high mean total sedentary time and relatively low to medium levels of mean perceived stress. This is in accordance with the findings of the descriptive analyses. Additionally, it seems that higher mean levels of total ST are not associated with higher mean levels of perceived stress. This correlates with the findings of RQ 1, where there was no significant relationship found between the variables total ST and perceived stress.

When visualising the EMMs of total ST and perceived stress over time (see figure 2), there seems to be a lot variation between the variables in the sample across time. Although the

levels of perceived stress did somewhat fluctuate across timepoints, it seems to stay between levels 2 and 6, never going towards the higher end of the scales despite higher levels or sudden drops in mean total ST. This correlates with the findings in RQ 1 where there was no significant effect between total ST and perceived stress.

Figure 1

Estimated marginal means for total sedentary time and perceived stress for each participant

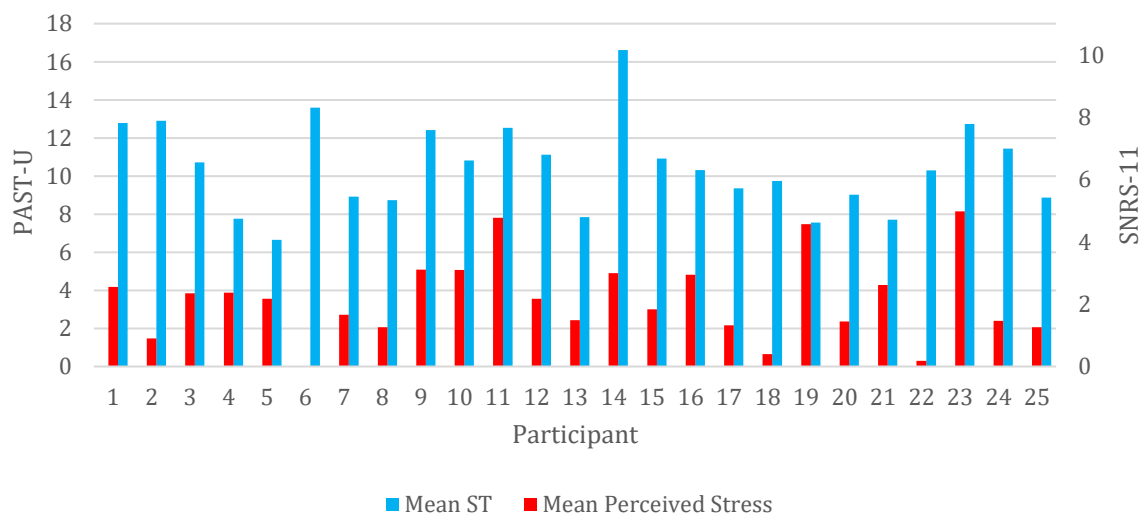
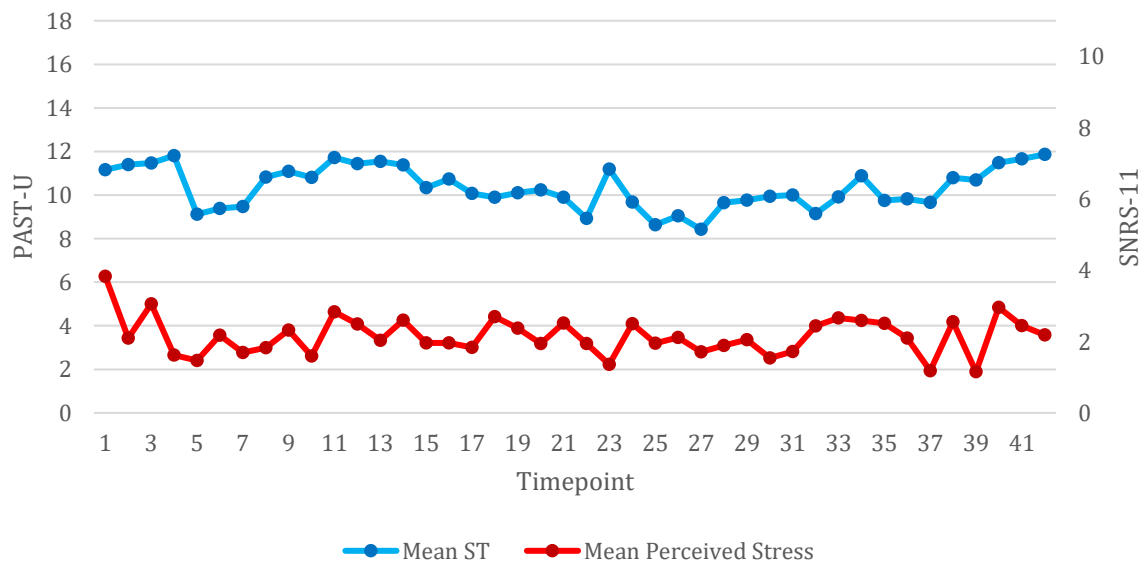


Figure 2

Variation of mean total sedentary time and mean perceived stress over time



Individual variation

The levels of perceived stress and total ST were visualised for a total of five participants. To view the figures, see appendix C. Whilst investigating the participants with the highest response rates, the fluctuations in total ST and perceived stress do not move in accordance with each other. In one participant they have average levels of stress and the amount of ST is relatively stable, whilst in two other participants it shows high levels of ST, but very low levels of perceived stress. Furthermore, levels of perceived stress would spike or lower regardless of whether total ST was stable, higher, or lower. The lack of correlation among all three participants seems to coincide with the findings of RQ 1, where no relationship was found between total ST and perceived stress.

Following this look at the participants with the highest response rate, an additional look was done at a participant with high trait rumination and a participant with low trait rumination. The participant with low trait rumination experienced low levels of stress despite relatively high levels of sedentary time. On the other hand, the participant with high rumination experienced moderate levels of stress even though their sedentary time was lower than the participant with low rumination. These visualisations correlate with the findings in RQ 2, where perceived stress and trait rumination was found to have a significant relationship. Finally, the visualisations also support the other findings in RQ 1 and RQ 2, where no relationship was found between sedentary behaviour and perceived stress. The fluctuations in total ST and state stress have a lot of variation, lacking correlation and thus sedentary behaviour and state perceived stress seem to be unrelated.

RQ 3: Between- and within-participant analysis

Between- and within-participant analyses were conducted in order to gain a deeper understanding of the analysed variables. For these analyses, linear mixed models were used. The analyses found that both total sedentary time PM ($b = 0.04$, $CI = [-.05, .14]$) and PMC (b

= 0.03, CI = [-.01, .07]) were insignificant factors of perceived stress (see table 5). This correlates with the findings found in RQ 1 and RQ 2 as well as the individual visualisations of participants.

Table 5

Summary of explorative analyses

Independent variable(s)	<i>F</i>	Estimate (<i>b</i>)	<i>SE</i>	<i>t</i>	<i>Sig.</i>	95% Confidence intervals	
						Lower bound	Upper bound
Sedentary Time PM	0.77	0.04	0.05	.87	.38	-0.05	0.14
Sedentary Time PMC	1.77	0.03	0.02	1.33	.18	-0.01	0.07

Note. Dependent variable = Perceived stress.

Discussion

The aim of this study was to highlight the possible relationship between sedentary behaviour and mental aspects such as rumination and perceived stress. It also investigated the fluctuations between sedentary time and perceived stress within participants and across time. Both the first analysis and the moderation analysis revealed that neither sedentary time or the interaction effect of trait rumination and sedentary behaviour had an association with perceived stress. However, a weak but significant positive relationship was found between perceived stress and trait rumination. Further analyses into the variables also revealed that the relationship between sedentary behaviour and perceived stress is neither on a between-participant or a within-participant level.

Implications

Effects of sedentary behaviour

The findings are somewhat surprising, as the mean sedentary time of students in this sample exceeded the average found by Castro et al. (2020) by 2 hours, and yet there seems to be no negative impact of this on their perceived stress levels. This is contradictory to other studies. Previous studies noted how sedentary behaviour could be associated with decreased (perceived) mental well-being, cognitive function, perceived feelings of stress, and increased psychological distress (Borojevic, 2016; Gibson et al., 2017; Saunders et al., 2020; Teychenne et al., 2019). A systematic review by Teychenne et al. (2019) could possibly explain the findings. Their systematic review noted that previous studies did not find an association between sedentary behaviour and perceived stress, but also that these studies were often low-quality. They recommended high-quality longitudinal studies be performed in order to better establish whether or not these findings are representative, something which this study attempts to do.

A possible further explanation is that there are variables surrounding SB that influence to what extent SB is associated with perceived stress. Teychenne et al. (2019) noted how the context and domain of sedentary behaviour could mitigate the negative effects on stress as a result from sedentary behaviour. In this study, students performed SB primarily in a leisure context. This might have mitigated the extent to which SB affects perceived stress. The findings by Zablotny (2022) also supports this theory. Their ESM-based study found that mentally passive sedentary time even reduced state perceived stress. Thus, it is possible that high levels SB itself are not enough to create more stress and that there are other moderating variables such as context or domain that affect the association between SB and perceived stress.

This study uses an ESM design, rather than a cross-sectional survey or independent research design. The ESM design of this study allows the variables to be examined over time, rather than at one point in time. As a result, variables can be examined on how they fluctuate over time and whether or not they are correlated with each other across time (Myin-Germeys et al., 2018). Cross-sectional studies by Weiß (2022) and Depenau (2022) failed to find a relationship between sedentary behaviour and perceived stress in a student sample. These findings are similar to the findings of this study, where no relationship was found. This coincides with Teychenne et al.'s (2019) findings, who noted that neither objective or self-reported measures proved to be better over the other in the context of SB and perceived stress. Therefore, the findings of this ESM study adds onto their findings, further supporting the notion that sedentary behaviour and perceived stress are unaffected by each other whether or not it was investigated momentarily or across time.

All in all, the lack of relationship between sedentary behaviour and perceived stress found in this study can be considered a positive outcome. With the amount of time students spend in SB, the lack of relationship is a hopeful outcome. Students tend to experience stress

often (Asif et al., 2020), but in this sample perceived stress levels were low on average despite high levels of SB. Although SB can still have negative effects on physical health and other mental health aspects such as mood and depression (Ellingson et al., 2018; Gibson et al., 2017; Saunders et al., 2020; Sheldon et al., 2021; Zhai et al., 2015), perceived stress seems to be unaffected. Factors such as context and domain may take precedent over high levels of SB by itself. Taking all of this into account, this study adds onto the evidence of whether sedentary behaviour and perceived stress are associated with each other and how this possible relationship is reflected in a student population.

Perceived stress and rumination

Aside from the findings between sedentary behaviour and perceived stress, a weak but significant relationship was found between perceived stress and rumination. This finding indicates that students with higher rumination levels perceive higher stress intensity or perceive higher levels of stress more often. This supports the findings of an association between rumination and perceived stress (Watkins & Roberts, 2020; Zoccola & Dickerson, 2012). However, the relationship in this study was weak.

A possible explanation for this is that rumination was measured only on a trait level, and not on a state level. A study by Du et al. (2018) measured state rumination and state perceived stress multiple times a day and their findings suggested that people who perceived higher levels of stress may also report more rumination. Findings by Willis and Burnett (2016) coincide with this suggestion, as they also reported that higher perceived stress was positively associated with ruminative behaviours. Therefore, although the relationship between trait rumination and perceived stress is significant, it is possible that the relationship between these two variables is stronger when investigated on a state level rather than on a trait level.

Strengths & Limitations

This study is one of the few studies investigating the direct relationship between sedentary behaviour and perceived momentary stress in an ESM design setting. By using experience sampling methodology the researchers were able to view the interaction between the variables over time, providing the opportunity for both a qualitative and quantitative analysis. ESM studies also have greater ecological validity, allowing the researcher to better use the findings in real life settings or interventions. The use of ESM also reduces the possibilities of memory bias, which proves useful in asking participants to recall their total sedentary time and perceived levels of stress (Scollon et al., 2003). Therefore, ESM can be considered the best approach for this study and allows it to get the most accurate data for analysis.

Over the duration of the study, several limitations were recognised. One of the limitations of this study is that some measurement items for the PAST-U had to be reformulated and combined in order to fit the repeated measures design of this study. Therefore, the lower reliability for the PAST-U in this study can possibly be explained by this. Another limitation is that during the course of using m-Path, several technical issues arose. It was not clear in the m-Path interface that scheduling a time frame did not automatically expire the survey if the timeframe had passed. This was discovered after two days and corrected afterwards. Because of this, some of the data had to be adjusted as some answers overlapped across dates. Another limitation is that the sample only includes higher education students and is therefore not generalizable to the overall population. These limitations could possibly have affected some of the data in this study and might not reflect the outcomes of similar studies in other sample populations.

Future Recommendations

Based on this study's findings, strengths, and limitations, recommendations for future research can be proposed. Future studies could focus on further investigating the relationship between sedentary behaviour and perceived stress, but on a sample of non-students. By expanding into various different sample populations, the findings could possibly further solidify the findings in this study. Furthermore, a longer study duration should be considered in future studies, so that multiple weeks can be compared with each other. This extended duration would allow for a more in-depth investigation into the relationship between the variables over time.

Alongside this, other methods should be considered in future research. Currently, this ESM study was based on repeated self-reports from participants, leading to possible recall bias and over- or underestimation of time spent in SB. Using measures such as inclinometers (e.g. activPAL) would possibly allow for more accurate measurements of total ST, whilst simultaneously reducing participant burden. This would in turn reduce recall bias and prevent possible misunderstandings of whether to report certain behaviours as sedentary behaviour. Furthermore, by reducing participant burden, the variables could be investigated for longer periods of time. Although self-reports of perceived stress are relatively reliable, future studies could attempt to measure physiological levels of stress. Doing this might help further solidify findings, result in different findings, or even allows for comparison between self-reported stress and physiologically measured stress.

Conclusion

To conclude this research paper, the findings of this study add to existing literature on sedentary behaviour and mental health. The findings indicate no relationship between sedentary behaviour and stress, which can be considered a positive finding. This was illustrated by the student sample, as they had high levels of SB and yet experienced relatively

low levels of perceived stress. However, students should make efforts to reduce their total time spent in SB, as it still has other negative physical and mental consequences.

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Appendices

Appendix A

Informed consent

Dear participant, We would like to thank you for taking part in our study! This study is conducted by Roos A.S. Kruk, Paula H. Naber, Ariya Solan, Edgar G. Avanisian and Mats O. Tebarth, and supervised by Gerko Schaap from the Department of Psychology, Health & Technology at the University of Twente.

The scope of this study is to investigate the relationship between **daily sitting time** and several variables including **mood, stress and anxiety**. You will help us address research gaps and contribute to a growing body of evidence regarding associations between sitting time and well-being. To participate, you need to be at least 18 years old, enrolled in a university or other higher education institution (HBO, Fachhochschule), and have proficient English language skills. Additionally, you need to be able to stand for at least 30 minutes a day and have access to and be willing to use a smartphone capable of running an app for the duration of the study.

For this study, we ask you to respond to four daily questionnaires for a duration of 14 consecutive days. On the first day of assessment, you will be asked to complete a baseline questionnaire. For the following days, you are required to respond to daily repeated questionnaires, scheduled at 10:00, 14:00, 18:00, and 21:00, each open for 2 hours.

Specifically, the questionnaire at 10:00 will ask you to retrospectively report on your sitting time from the previous day, while the remaining three questionnaires will ask you about specific conditions such as mood, stress, and anxiety. All questionnaires will be completed via the m-Path app.

There are no physical risks associated with this research project. Regarding the time period of two weeks, you may have timely constraints and not enough energy to constantly fill in the questionnaires. If any of these cases apply, you may withdraw at any given time as your participation in this study is voluntary. In the case of additional complaints, you can contact the researcher(s). Keep in mind that in the case of early withdrawal, you will **not be granted any SONA credits**.

All personal data will be anonymised and kept confidential. The data will only be used for the purpose of this study and will be stored on researchers' devices for a period of two years.

Please do not hesitate to contact the researchers if you have any questions or concerns before, during or after your participation:

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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 Information & Computer Science: ethicscommittee-CIS@utwente.nl

Do you agree to all of the above-mentioned statements and confirm that you consent to take part in this study and for your data to be used for future research as described?

Please select one of the following options:

- I agree

- I disagree

Appendix B

Finalised list of items used for data collection

Baseline Questionnaire

Demographics	Question	Answer options
Item 1	What is your gender?	1) Female 2) Male 3) Other 4) Prefer not to say
Item 2	What is your age?	Numerical value
Item 3	What is your nationality?	1) Dutch 2) German 3) Other, please specify:
Item 4	What is your current occupation?	1) Enrolled at a university 2) Enrolled at another higher education institution (HBO, Fachhochschule) 3) Other
Item 5	Are you able to stand for 30 minutes at a time without any support?	1) Yes 2) No
Item 6	If you are participating via Sona, please indicate your SONA ID	Numerical value
Trait Rumination	Questions	Answer options

Item 1	How often do you think “What am I doing to deserve this?”	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 2	How often do you think “Why do I always react this way?”	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 3	How often do you think about a recent situation, wishing it had gone better?	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 4	How often do you think “Why do I have problems other people don’t have?”	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 5	How often do you think “Why can’t I handle things better?”	1) Almost never 2) Sometimes 3) Often 4) Almost always

Item 6	How often do you analyse recent events to try to understand why you are depressed?	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 7	How often do you go away by yourself and think about why you feel this way?	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 8	How often do you write down what you are thinking and analyse it?	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 9	How often do you analyse your personality to try to understand why you are depressed?	1) Almost never 2) Sometimes 3) Often 4) Almost always
Item 10	How often do you go someplace alone to think about your feelings?	1) Almost never 2) Sometimes 3) Often 4) Almost always

Repeated Questionnaire Measuring Total ST (PAST-U), 30-min ST, Context/Type, and States Scheduled at 10:00

For clarification:

In this survey, we are only interested in behaviour while you were sitting or lying down and being awake! Standing or other positions are not of interest here! Furthermore, sport in a seated position is also not of interest here as we are investigating sitting behaviour without physical activity!

Total ST (PAST-U)	Questions	Answer options
Item 1	How long were you sitting while <u>studying/working yesterday?</u> (Include the time at University, during lectures, tutorials, meetings, group discussions, study/work from home, etc.)	Numerical value
Item 2	How long were you sitting for <u>transportation/travelling yesterday?</u> (Include sitting and waiting for transport. Do not include any time you were standing up while travelling or waiting.)	Numerical value
Item 3	How long were you sitting or lying down while <u>watching TV, internet-use or playing video games yesterday?</u> (Include watching TV, playing video games, internet-use for activities that were not for studying or working purposes, like social media, Netflix, YouTube, online shopping, etc.)	Numerical value

Item 4	How long were you sitting or lying down while <u>reading</u> during your leisure time yesterday ? (Include reading in bed but do not include time spent reading for work or study)	Numerical value
Item 5	How much time did you spend sitting down for <u>eating</u> and drinking yesterday ?	Numerical value
Item 6	How much time did you spend yesterday sitting down to <u>socialize</u> with friends or family, regardless of location? (Include at University, at home, or in a public place, etc. Include time on the telephone)	Numerical value
Item 7	How much time did you spend yesterday in any <u>other</u> sitting or lying behaviour that you may have done but not yet told us about? (e.g., hobbies such as doing arts and crafts, playing board games, listening to music, or religious purposes)	Numerical value
State Stress		
Item 1	What number describes your stress over the past <u>30 minutes</u> ?	Scale of 0 to 10, 0 being no stress and 10 being worst stress possible (11-point-likert scale)

Repeated Questionnaire Measuring 30-min ST, Context/Type, and States Scheduled at 15:00 and 20:00

State stress	Questions	Answer options
Item 1	What number describes your stress over the past <u>30 minutes</u> ?	Scale of 0 to 10, 0 being no stress and 10 being worst stress possible (11-point-likert scale)

Appendix C

Visualisations of individual participants

Figure C1

Variation over time for participant 1

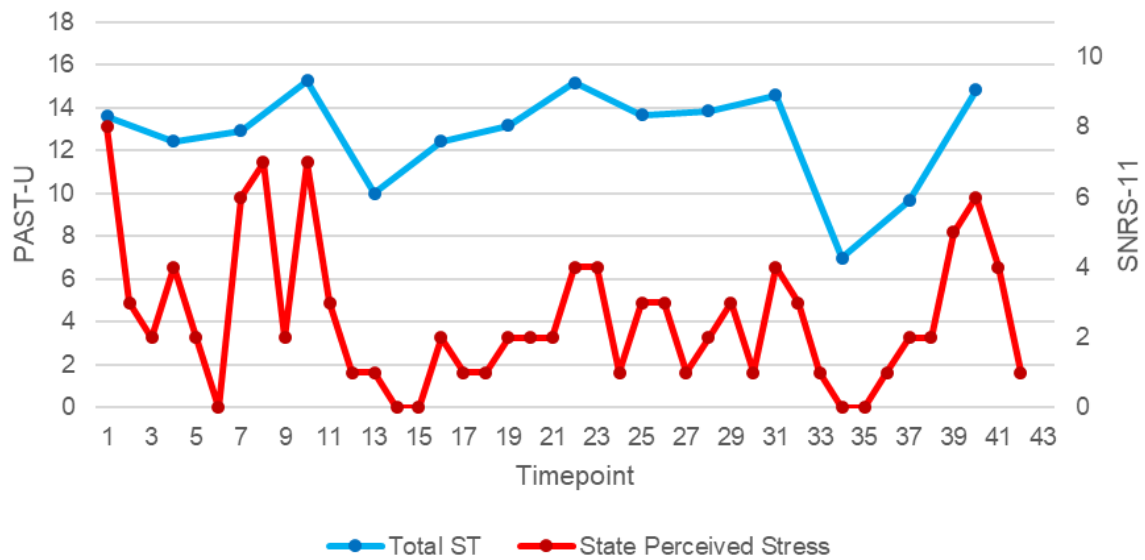


Figure C2

Variation over time for participant 23

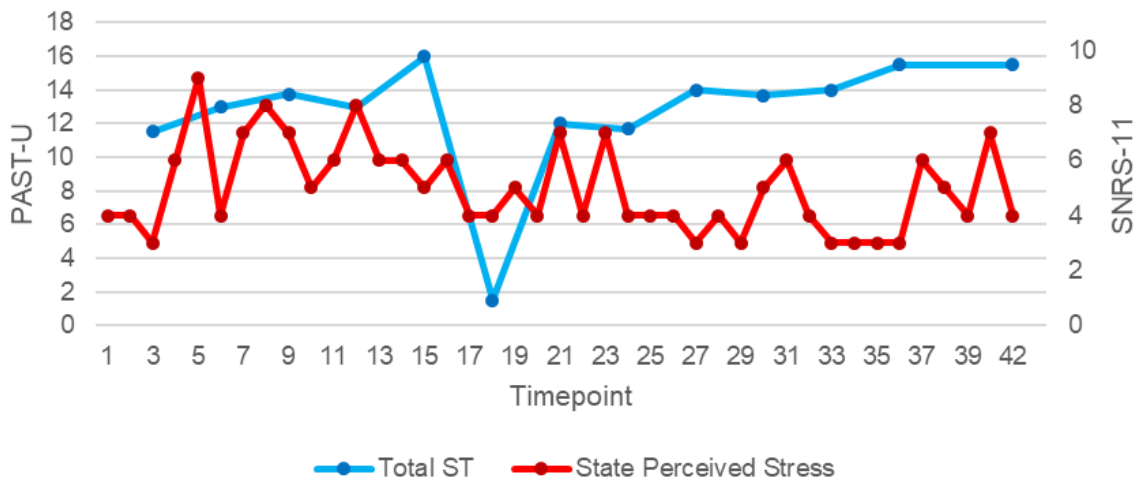


Figure C3

Variation over time for participant 24

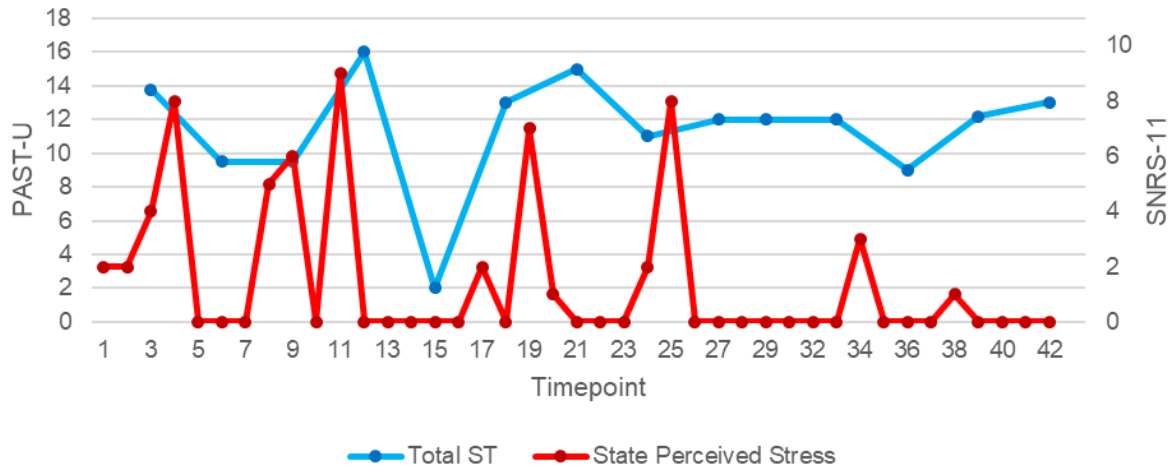


Figure C4

Variation over time for participant 24 (low trait rumination)

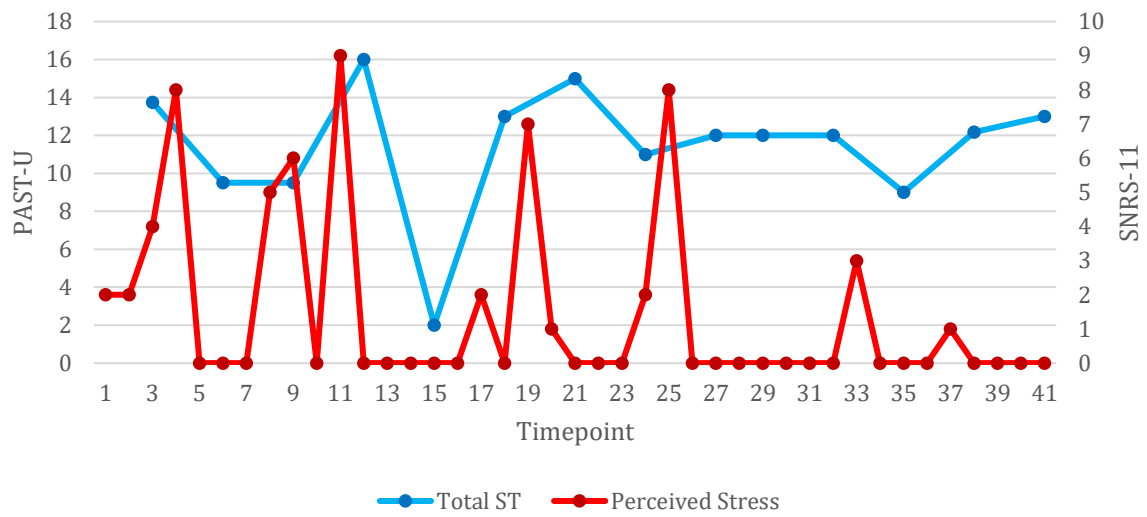


Figure C5

Variation over time for participant 19 (high trait rumination)

