Exploring the Moderating Role of Resilience on the Relationship between Sedentary Time and Perceived Stress: An Experience Sampling Study

Izgen Ariya Solan (s2712628)

Programme of Psychology, University of Twente

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1st Supervisor: Gerko Schaap

2nd Supervisor: Dr. Peter ten Klooster

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Abstract

Considering that university students sit more than the average adult population, investigating how sedentary behaviour is associated with perceived stress levels over time is important to promote student health. The current study aimed to investigate how short-term and daily average sedentary time (ST) are associated with perceived stress over time, examining variations at a within- and between-person level. Resilience was investigated as a potential moderator of this relationship. Therefore, an experience sampling methodology was conducted with 25 students (M_{age} = 21.68 (SD_{age} =2.61) years, 56% Men) who filled in three daily questionnaires for a period of two weeks. Linear mixed models showed that the relationship between ST and perceived stress was not significant (B = 0.032, SE = 0.021, 95% CI [-0.009, 0.072]). Furthermore, only for the 30-min ST scale, significant between-person associations were found (B = -0.87, SE = 0.033, 95% CI [-0.153, -0.022]). Resilience was not a moderator on the overall relationship between ST and perceived stress (p =0.098). However, there was a significant negative relationship between resilience and perceived stress (B = -0.133, SE = 0.26, 95% CI [-0.184, -0.082]). Visualizations at a sample and individual level supported these findings. Thus, although ST was not significantly associated with perceived stress, the longitudinal design revealed a more pronounced association when comparing short-term ST and perceived stress across students. These findings highlight the complexity of the ST and perceived stress relationship, which can inform future research to investigate further factors that might influence these variables in university students.

Keywords: sedentary time, perceived stress, resilience, experience sampling methodology

Exploring the Moderating Role of Resilience on the Relationship between Sedentary Time and Perceived Stress: An Experience Sampling Study

In modern society, technological advancements and digital communications have profoundly increased the sedentary behaviour (SB) of people while studying, working, travelling, and spending their leisure time (Dunstan et al., 2010). SB is different from physical inactivity. While the latter refers to the absence of physical activity, the former refers to behaviours characterized primarily by sitting or being in a reclining posture with levels of metabolic energy expenditure being lower than or equal to 1.5 while being awake (Dempsey et al., 2020; Tremblay et al., 2017). SB can occur in different domains of daily life, such as while watching TV, using the computer at the workplace, studying, reading, or meeting friends (Bauman et al., 2017; Owen et al., 2011). Consequently, *sedentary time* (ST) refers to the amount of time spent in any form of SB, often quantified in hours per day (Tremblay et al., 2017). According to a meta-review conducted by Bauman et al. (2017), adults engage in an average ST of 8.2 hours daily. Although, on average, students sit more than most adults, the recent COVID-19 pandemic significantly increased the ST of university students, with their daily average reaching eleven hours during the pandemic (Bertrand et al., 2021). The increase in online education and remote learning may have had a long-lasting effect on this, as there has been a sustained increase in ST across Europe beyond lockdown measures (Beller et al., 2023). Hence, SB is an increasing cause for concern, especially for students of higher education.

There is a growing body of research investigating the consequences of ST. Patterson et al. (2018) conducted a meta-analysis of 34 studies and identified a threshold of six to eight hours of total ST a day as a significant risk factor for adverse health consequences that tend to persist in the long run. Independent of a lack of physical activity, prolonged ST has been associated with increased risks for all-cause mortality, cardiovascular disease, cancer, metabolic diseases, obesity, and type two diabetes (Patterson et al.,2018; Tremblay et al., 2010). Besides physical health risks, there is an increasing recognition of the influence of ST on mental health. Research has shown that prolonged ST may increase the likelihood of developing mental health problems, such as depression and anxiety (Lee & Kim, 2018; Teychenne et al., 2015; Zhai et al., 2014). These health problems may be caused by factors such as disturbed sleep patterns and decreased social interactions, which are both linked to SB (Werneck et al., 2019). Though the possibility that prolonged sitting could have an impact on mood and mental health is of increasing concern,

the exact nature of this relationship remains unclear. Thus, understanding the mechanisms by which ST affects mental health is essential for promoting psychological well-being and decreasing mental and physical health problems in society.

While the specific mechanisms underlying the link of ST to mental health are not fully investigated yet, there is substantial evidence that ST may be associated with an increase in *perceived stress* (Dėdelė et al., 2019; Silva et al., 2018). Perceived stress can be defined as the subjective appraisal of how challenging, overwhelming, or stressful certain situations are perceived in one's life (Cohen et al., 1983). Sliwinski et al. (2009) differentiate between components of perceived stress that are stable (trait perceived stress) from those that are more variable (state perceived stress). Trait perceived stress refers to an individual's characteristic to perceive and appraise situations as stressful over time, while state perceived stress is more variable and refers to the experience of stress in response to a specific situation. Previous research often focused on trait perceived stress, creating a gap in the literature that this study aims to address.

Students of higher education are particularly affected by elevated levels of perceived stress. In the Spring 2019 Health Assessment by the American College Health Association (ACHA), 45.3% of undergraduate college students indicated having experienced more than average stress over the past 12 months, while 34.2% indicated that stress was their primary barrier to learning. In general, elevated levels of perceived stress can impair the ability to pay attention and concentrate, potentially leading to stress-induced psychopathology. Moreover, the consequences of stress can affect daily functioning at work or school (Southwick et al., 2005). A study conducted by Silva et al. (2018) demonstrated that higher ST may lead to dissatisfaction of relationships with peers and family, potentially explaining the positive correlation between ST and perceived stress. Another explaining factor may be the social isolation that results from SB, which may accentuate the negative impact of stressors (Werneck et al., 2019). These factors may exacerbate the perceived stress of university students, who are already at risk of developing mental health implications due to the stressors of their daily lives (Lee & Kim, 2018). However, literature on this topic has primarily focused on cross-sectional designs, leaving a gap on how these variables relate over time, especially within students.

To gain a better understanding of the relationship between ST and perceived stress, it is essential to consider within-person and between-person associations. Within-person associations

refer to the variations of certain variables within the same individual across different time points (Molenaar & Campbell, 2009). These associations can help identify how an individual's ST is associated with their perceived stress levels over time. Conversely, between-person associations refer to the variability of ST and perceived stress across different individuals (Curran & Bauer, 2011). The investigation of between-person associations can enable a more comprehensive view of whether individual traits may contribute to variations in these variables (Hedeker et al., 2012). As a result, both within- and between-person associations are crucial to draw more informed conclusions about the relationship between ST and perceived stress.

An experience sampling methodology (ESM) can be suitable for investigating within- and between-person associations of ST and perceived stress. ESM is an intensive longitudinal self-reported design that provides momentary assessments of psychological constructs and behaviours in the real-life context, potentially offering more reliable and valid data compared to traditional self-reports (Myin-Germeys et al., 2018). Therefore, ESM can minimize the influence of memory biases and provide ecologically valid data, especially on the within-person association of state variables like ST and perceived stress. Moreover, ESM provides the opportunity to investigate how variables interact within subjects over time, as well as associations across subjects (Hedeker et al., 2012). Nonetheless, there is limited research on the use of ESM to investigate the relationship between ST and perceived stress. For instance, Pinto et al. (2020) identified a positive relationship between the two variables. However, the study was only conducted among breast cancer survivors. Therefore, there remains a gap in the literature, emphasizing the need for ESM studies to further explore the relationship between ST and state perceived stress in students of higher education.

While the main factors influencing how perceived stress relates to ST are not fully investigated yet, the *trait resilience* may impact this relationship. According to Diehl et al. (2012), resilience can operate as a buffer against the negative impact of daily stressors, eventually leading to a decrease in perceived stress. Although most studies focus on resilience in the face of major life events and chronic stress, investigating the role of resilience when facing daily stressors is crucial to promote long-term well-being. According to the American Psychological Association (APA, 2018), resilience is “the process and outcome of successfully adapting to difficult or challenging life experiences”. While resilience is often conceptualized as an enduring trait, understanding resilience as a process as much as an outcome reflects a more

dynamic nature (Connor & Davidson, 2003; Lee et al., 2013). Resilience is more than the process of adapting well; it is also the outcome of flourishing after overcoming adversity and maintaining the adaption to stressful situations over time (APA, 2018). Therefore, resilience can be operationalized as a psychological trait that promotes positive adjustment in the face of challenging circumstances, diminishing the amount of perceived stress over time.

Although previous research has investigated the relationship between ST and perceived stress, a gap exists in the literature regarding how they relate over time and when accounting for the trait resilience. Hence, for the aim of investigating the relationship between perceived stress and ST, both short-term ST, specifically for the past 30 minutes, as well as ST as a daily average was chosen, alongside examining the moderating role of resilience. A time frame of the past 30 minutes was used to capture immediate ST and its potential immediate impact on perceived stress, complementing the broader perspective provided by daily average ST measurements. Considering that ST and perceived stress have previously been shown to be positively correlated and have a negative impact on mental health, university students can be viewed as a potentially vulnerable group as they are more sedentary than the normal population and experience above-average stress levels (Bertrand et al., 2021; ACHA, 2019).

Therefore, the following research question will be investigated in this study: *How are ST and perceived stress related among university students over time? (RQ1)* Based on existing literature, it is expected that a general increase in ST will result in increased perceived stress. Moreover, the sub-questions *How is the within-person relationship between sedentary time and perceived stress among university students over time?* and *How is the between-person relationship between sedentary time and perceived stress among university students?* will be addressed to gain more insights into the dynamic nature of the variables and understand possible reasons for fluctuations.

Furthermore, the main research question of this study will be: *To what extent does the trait resilience moderate the overall relationship between sedentary time and perceived stress over time among university students? (RQ2).* Investigating how resilience moderates the overall relationship between ST and perceived stress in university students can lead to significant improvements in their long-term well-being. The focus will be on the overall association between short-term and daily ST with perceived stress in the entire dataset without distinguishing the source of variability. Research suggests that students with higher levels of trait

resilience may cope more effectively with the stressors induced by ST, thereby resulting in a decrease in perceived stress (Diehl et al., 2012). Thus, the relationship between ST and perceived stress is expected to be significantly lower in students who have high resilience. By investigating these research questions, this research aims to contribute to the understanding of how ST is associated with perceived stress in students of higher education.

Methods

Design

To investigate the relationship between ST and perceived stress in a real-life setting, an ESM study was implemented. An ESM prompts participants to report on their behaviours and experiences close to when they occur, thereby reducing potential memory biases. For this study, a time-contingent design using a fixed schedule on a smartphone application was chosen to systematically capture data points, minimize variability in response times, and enable a more accurate assessment of the variables. To achieve this, participants were asked to fill out different questionnaires in given time frames. The design enabled a comprehensive assessment of fluctuations in the state variables of ST and perceived stress within and between participants over time (Myin-Germeys et al., 2018). Specifically, three questionnaires were sent daily, one morning questionnaire at 10 am, one afternoon questionnaire at 3 pm and an evening questionnaire at 8 pm.

According to Van Berkel et al. (2017), ESM studies typically last between one to three weeks. To capture behavioural patterns over time and increase reliability, the midpoint of this range was chosen, specifically, a duration of two weeks. In cooperation with other researchers, data was collected by combining several questionnaires in the same app. Ethical approval was received from the BMS Ethics Committee of the University of Twente on the 20th of March 2024 (request nr.: 240234). The study was published on the 30th of March at the SONA Systems website of the University of Twente. All participants started the study on the 8th of April 2024 until the 23rd of April 2024.

Participants

Participants were recruited via convenience sampling using the test subject pool SONA Systems, granting three credits at the end of the study as an incentive for participation. Additionally, participants were recruited in the researchers' networks via WhatsApp, Instagram, and Discord.

Inclusion criteria specified that participants should be proficient in English, at least 18 years old, and have access to and willing to use a smartphone for the period of the study to qualify for participation. Furthermore, as the target group consists of students of higher education specifically, participants needed to study at a university, hbo or Fachhochschule.

To ensure accurate inferences, participants with a response rate lower than 50% were excluded from the analysis (Conner & Lehman, 2012). Moreover, participants who could not stand for more than 30 minutes and were bound to a wheelchair needed to be excluded from the analyses. This left a final sample of 25 participants, which is in line with the finding of Van Berkel et al. (2017), who found a median of 19 participants across a numerous ESM studies. The sample included 14 male (56%) and 11 female participants (44%). Fourteen participants were of German nationality (56%), seven of Dutch nationality (28%) and four were from other nationalities (16%). Participants' ages ranged between 18 to 29 (M = 21.68, SD =2.61) years.

Materials

Recent studies suggest that using smartphones enhances the effectiveness of ESM studies. Van Berkel et al. (2017) highlight that smartphones offer real-time monitoring of study progress, facilitating the identification and resolution of potential research design issues. Additionally, smartphones enable researchers to gather rich qualitative insights into participants' daily experiences. Thus, participants were asked to complete different questionnaires using their smartphones via the m-Path App. M-Path is designed to get insights into the everyday life of people, making it suitable for an ESM (Mestdagh et al., 2023).

Baseline Questionnaires

A baseline questionnaire (Appendix A) was implemented in m-Path to collect demographic data, like gender, age, nationality, and current level of education. Moreover, as the third research question focused on the moderating role of the trait resilience, it was only measured once. Therefore, the baseline questionnaire included the 10-item Connor–Davidson Resilience Scale (CD-RISC-10) to assess the participant's resilience level. The answer option was a 5-point Likert scale, with options ranging from "strongly disagree" to "strongly agree". This questionnaire was chosen over the original 25-item CD-RISC, as a longer questionnaire might impede voluntary participation. Nevertheless, it demonstrated high correlation (r =.92) to the original 25-item CD-RISC questionnaire with good reliability (α = .85) and good construct validity (Campbell-Sills & Stein, 2007).

Sedentary Time

Furthermore, the state measure of ST needed to be assessed to draw inferences about its relationship with perceived stress. To explore the daily average ST, the Past-Day Adult's Sedentary Time - University (PAST-U) was implemented. The PAST-U is a nine-item questionnaire specifically designed to assess the time university students spend sitting or lying down in the context of study, work, leisure time, or other activities, during the previous day. To assess its validity, the results were compared to an objective measurement of ST, the activPAL which demonstrated acceptable criterion validity (intraclass correlation coefficient = .64, mean difference = 0.08h, *SD* = 2.04h; Clark et al., 2016). However, to maximize the daily response rate while also maintaining as many of the psychometric properties as possible, the study aimed to keep the items as brief and concise as possible. Considering the content of the first and second item, namely ST in the context of studying and working, these two contexts were fused into one single item to minimize redundancy and participation burden: "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.)". Moreover, the fourth and fifth items measure watching TV and using the computer, respectively. Since playing video games and watching Netflix are often used interchangeably on TV and the computer, these two items were also combined. Therefore, the adapted version of the PAST-U included seven items to measure the total ST of the previous day. As the questions refer to the previous day, the questionnaire was only asked in the morning. The wording of most items was refined to fit the screen on the m-Path app (Appendix B).

To also explore the relationship between ST and perceived stress at a short-term level, the question "Over the past 30 minutes before the notification, how many minutes have you been in a sitting or reclining position?" (30-min ST measure) was added to the morning, afternoon, and evening questionnaire.

Perceived Stress

Perceived stress was measured using the stress numerical rating scale-11 (SNRS-11), which is a single-item measure for adolescents and adults. As it is comprised of one item, it is a suitable questionnaire for conducting experience sampling of the repeated state measure of perceived stress. The item is "What number describes your stress over the past 30 minutes?" with answer options ranging from 0 (no stress) to 10 (worst stress possible). Research has shown that

the SNRS-11 has moderate concurrent validity and moderate to strong construct validity (Karvounides et al., 2016). To explore fluctuations throughout the day, the question was included in all three questionnaires daily.

Procedure

Participants could access the study via a link that was either shared on social media websites or presented on the SONA systems website. By accessing the link participants were directed to install the m-Path app, enter their participation code, and enable the notifications on their phones. After collecting participants for two weeks, the study started simultaneously for everyone on 8th April with a notification for the baseline questionnaire. Table 1 provides an overview of the fixed sampling schedule over the 14 days, including the initial day for the baseline questionnaire.

On the first day, the participants received an online consent form with the option to either agree or not agree to the terms and conditions of the study (Appendix C). After accepting the informed consent participants were presented with the demographic questions and the 10-item CD-RISC. The first questionnaire of the SNRS-11 and the 30-min ST measure was sent the day after the baseline questionnaire at 10 am. Participants again received a reminder after an hour and the questionnaire was closed after two hours. At 3 pm and 8 pm, the same questionnaire was sent again both being open for two hours and sending a reminder after one hour. The next day at 10 am, the first morning questionnaire was presented which included the revised version of the PAST-U, the SNRS-11, and the 30-min ST measure. Similar to the other questionnaire this one was open for two hours sending a reminder after 60 minutes. The repeated measure for perceived stress was presented like the day before both at 3 and 8 pm. This schedule was repeated for the following 12 days. As the PAST-U assesses the ST of the previous day, on the last day, only the PAST-U was presented to the clients from 10 am to 10 pm. After completing each questionnaire, participants were presented with a “Thank you for filling in this questionnaire! :D” page.

Table 1

Overview of Questionnaires and the Procedure

Date	10 am – 12 am	3 pm – 5 pm	8 pm – 10 pm
08.04		Baseline Questionnaire	
09.04 - 22-04	Morning Questionnaire	Afternoon Questionnaire	Evening Questionnaire
23-04		Only PAST-U	

Note. Morning Questionnaire = Past - Day Adult's Sedentary Time - University (PAST-U), stress numerical rating scale-11 (SNRS-11) & 30-min ST measure. Afternoon and Evening Questionnaire = SNRS-11 & 30-min ST measure.

Data Analysis

To investigate the research questions the data was exported from m-Path, transferred into a long-format Excel file, and initially cleaned by excluding participants who did not fulfil the inclusion criteria. For the 30-min ST questions, responses from participants who consistently reported ST in hours instead of minutes were adjusted to ensure they did not exceed 30 minutes. Regarding the scores of the PAST-U, responses exceeding 18 hours of ST appeared unrealistic given the need for individuals to be awake. Consequently, these observations were adjusted to a maximum of 18 hours. Since the PAST-U assesses the total ST of the previous day, the time of measurement needed to be lagged to the preceding day to coincide with the perceived stress measure.

The cleaned dataset was imported into SPSS Version 29. Having analysed the demographics and descriptive statistics, Cronbach's Alpha was calculated for the CD-RISC-10 (Campbell-Sills & Stein, 2007). For the repeated measures of SNRS-11, 30-min ST, and PAST-U, split-half reliability analysis was conducted by calculating the Pearson correlation of the average momentary scores of the first and second weeks.

To visually analyse the ESM responses, Estimated Marginal Means (EMMs) across time points and per participant were calculated for ST and perceived stress. Further visualizations included the ST scales and perceived stress levels of two participants with high response rates, one of which scored high on the CD-RISC-10 and another participant who scored low on the same measure.

To statistically investigate the research questions, Linear Mixed Models (LMMs) were implemented. LMMs take into account the nested structure of the data arising due to repeated observations within the same participants. The restricted maximum likelihood (REML) estimations used in the LMM can account for time-varying covariates and missing data (Krueger & Tian, 2004). All LMMs were implemented by defining the timepoint as the repeated measurement, participants as the subject variable and perceived stress as the dependent variable. The autoregressive covariance structure AR (1) was set for the LMMs to account for the assumption that the correlation of the measurements within participants diminishes over time (IBM, 2019).

To investigate the relationship between ST and perceived stress (RQ1), LMMs were conducted with both 30-min ST and total ST separately as the independent variable. Moreover, to investigate the statistical significance of between-person associations, the person mean (PM) was calculated by aggregating each ST measure by participant. For within-person associations, the person mean centred estimates (PMC) were calculated by subtracting the personal mean from each ST (Curran & Bauer, 2011). Subsequently, both PM and PMC scores were put into one LMM as fixed covariates.

Finally, to investigate the moderating role of resilience on the relationship between ST and perceived stress (RQ2), an LMM with resilience, total daily ST and the interaction term of both were set as the independent variables.

Results

Descriptive statistics

Sample Characteristics

In the final sample, the average response rate was 83.9%, resulting in 826 observations in total. Three participants consistently reported the 30-min ST scale in hours instead of minutes, so their responses were corrected accordingly. Regarding the total ST, 16 responses exceeding 18 hours were adjusted to a maximum of 18 hours, while one observation at 18.36 hours remained unaltered as it appeared realistic.

Table 2 displays the general characteristics of the sample. Reliability analysis for the CD-RISC-10 revealed moderate internal consistency ($\alpha = .66$). The trait resilience was relatively high in the sample ($M = 26.68$, $SD = 4.01$) with a maximum of 36 and a minimum of 20. The split-half reliability analysis for the SNRS-11 revealed very strong reliability ($r = 0.902$). Perceived

stress was very low in the sample (M = 2.21, SD = 2.28) with a minimum of 0 and a maximum of 10. For the 30-min ST measure the split-half reliability was weak (r = 0.315). The maximum amount of ST for the past 30 minutes was 30 and the minimum was 0 (M = 21.31, SD = 11.00). For total ST, the sample mean was relatively high (M = 10.62, SD = 4.71) with a minimum of 0.2 hours (12 minutes) and a maximum of 18.37 hours. However, the split-half reliability of the PAST-U was weak (r = 0.393).

Table 2

Descriptive statistics of Trait Resilience, Perceived Stress, 30-min ST, and Total ST

	n	M	SD	Min	Max
Trait resilience	25	26.68	4.01	20	36
Perceived stress	823	2.21	2.28	0	10
30-min. ST	826	21.31	11.00	0	30
Total ST (hours)	665	10.62	4.71	0.2	18.37

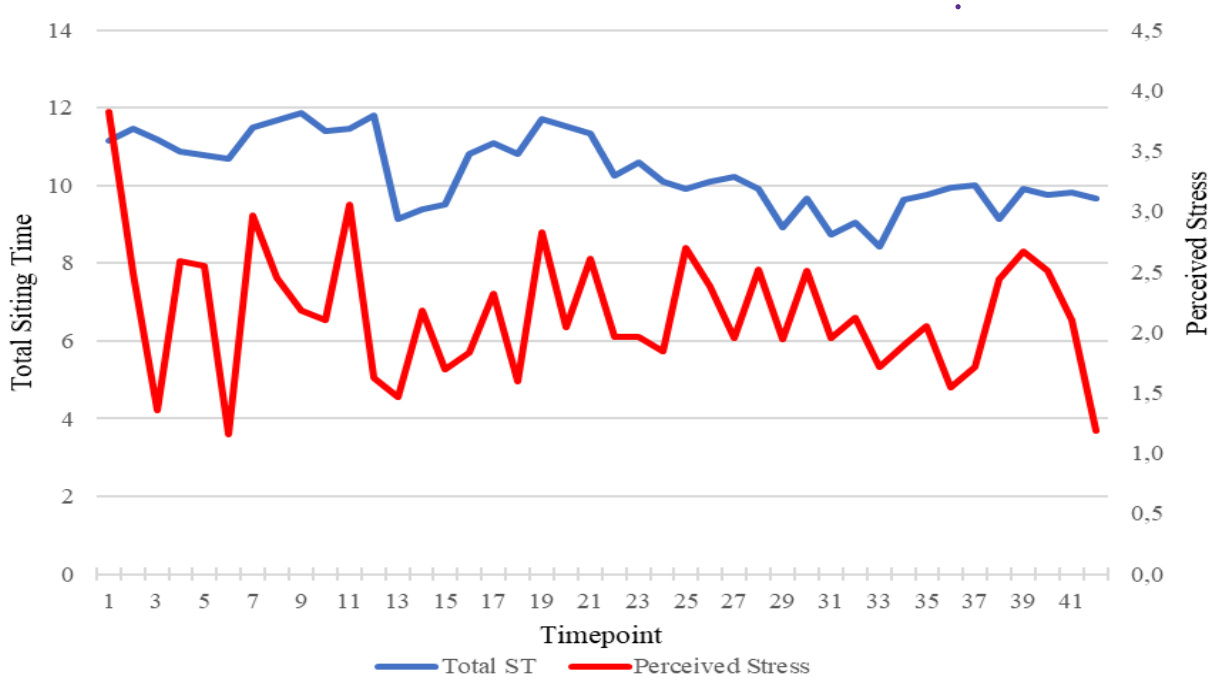
Note. M= Mean; SD = Standard Deviation.

Variations of Sitting Time and Stress in the Sample over Time

To illustrate the relationship between ST and perceived stress over time EMMs were plotted over time (Figure 1). In general, perceived stress seems to be lower in the evenings (T3, T6, T9, T12, etc.) and during both weekends (T13-T18 and T34 -T39). Although the variations of both ST and perceived stress are minor, no clear covariance was observable between the two variables over time. However, there are some similarities in the temporal trajectory of perceived stress with total ST, i.e. in Figure 1 at T12-T17, T29-34. Notably, the correlation from T13 to T17 in Figure 1 represents the first weekend from Saturday (T13-15) to Sunday (T17-T18). However, this correlation is not apparent in the second weekend (T34-T39). This was not the case for the 30-min ST scale (see Figure D1).

Figure 1

Estimated Marginal Means of total ST and perceived Stress over 42 Measurement Points

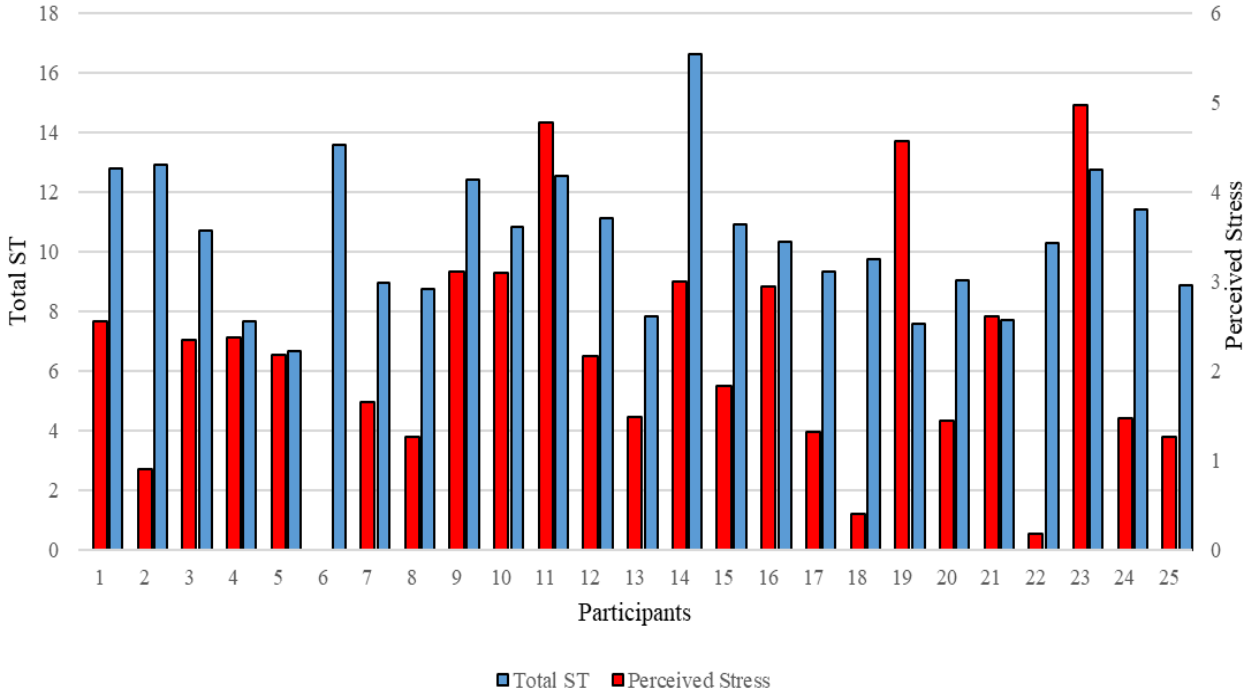


Variations of Sitting Time and Stress in the Sample between participants

Figure 2 illustrates the EMMs of the total ST and perceived stress over all 25 participants. Overall, the discrepancies between the two variables differ considerably between participants, i.e. for P6 the EMM for perceived stress is the lowest in the sample with total ST at 13.6 hours, while for P23 the total ST is 12.74 hours, but the perceived stress score is the highest in the sample. Considering that 30-min ST showed similar tendencies (see Figure D2), the correlation between total ST and 30-min ST was investigated, revealing a significant correlation between the two measures (B = 0.325, *SE* = 0.093, 95% CI [0.141, 0.508]). However, further analysis revealed significant differences between total ST and 30-min ST by participant (F (24, 395) = 1.76, p = 0.016). Therefore, while the 30-min ST and total ST measure are correlated, they display differences at the between-participant level, as indicated by the EMMs.

Figure 2

Estimated Marginal Means of total ST and perceived Stress for all 25 Participants

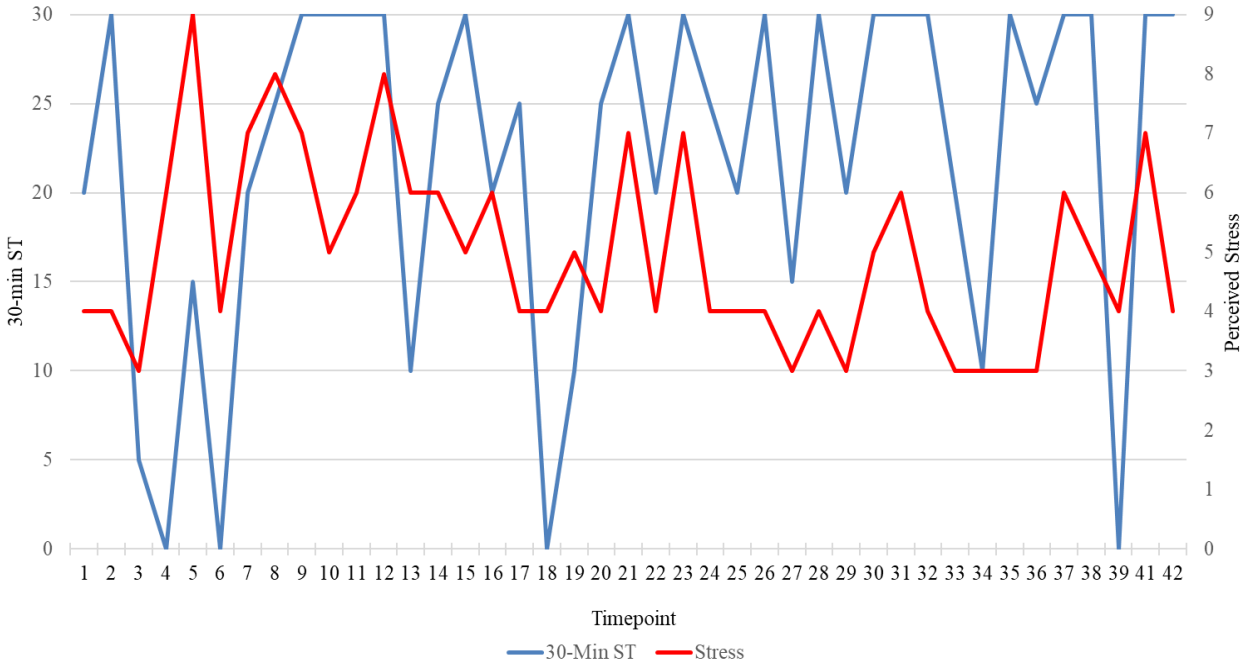


Individual Case Visualisations

Participant 23. Participant 23 had a response rate of 98% and a score of 20 on the CD-RISC-10. Therefore, this participant had the lowest resilience score in the sample. The perceived stress score was 5.1 which is higher than the mean of the total sample. However, ST over the last 30 minutes was on average 21.83 which is close to the total sample mean. Figure 3 illustrates that on both Sundays, perceived stress increases in the mornings (T16 and T37) and decreases back towards the evenings (T18 and T39). 30-min ST shows the same pattern only on the second Sunday. Thus, there does not seem to be a consistent pattern in the relationship between ST and perceived stress for this participant.

Figure 3

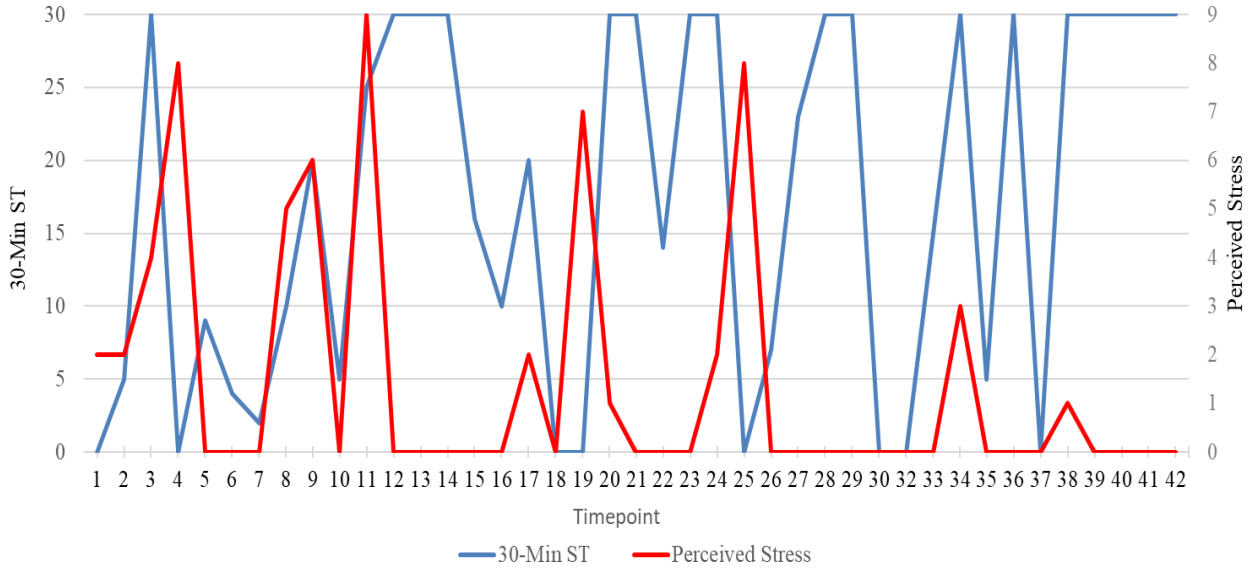
30-min Sitting Time and Perceived Stress for Participant 23



Participant 24. Participant 24 also had a response rate of 98% and achieved the highest score of 36 on the CD-RISC-10 in the sample. Moreover, the mean perceived stress score of 1.5 was very low compared to the sample mean, while the 30-min ST mean of 17.07 was average. Figure 4 shows that perceived stress scores were most of the time at zero, while 30-min ST showed more fluctuations. Similar to Participant 23, these fluctuations do not seem to be related to perceived stress scores or any time points during the day. Figure D3 and Figure D4 show that total ST did not fluctuate as much as 30-min ST, while still, no pattern was apparent in relation to perceived stress.

Figure 4

30-min Sitting Time and Perceived Stress for Participant 24



RQ1: Relationship between Sedentary Time and Perceived Stress

Table 3 gives an overview of all LMMs conducted with total ST to investigate the different research questions. Table D1 shows the same analysis with the 30-min ST scale. Against expectations, the relationship between total ST and perceived stress was not significant (B = 0.032, SE = 0.021, 95% CI [-0.009, 0.072]). A similar non-significant association was found for 30-min ST (B = 0.006, SE = 0.007, 95% CI [-0.007, 0.019]).

When further investigating the relationship between total ST and perceived stress over time, no significant association was found within students, neither for total ST (B = 0.029, SE = 0.022, 95% CI [-0.015, 0.074]) nor for 30-min ST, (B = 0.10, SE = 0.007, 95% CI [-0.003,

0.024]). The results are in line with the individual visualizations, as the fluctuations do not indicate consistent patterns within participants.

Moreover, no significant association between students was found for the total ST measure (*B* = 0.044, *SE* = 0.022, 95% CI [-0.056, 0.144]). However, for the 30-min ST, a significant negative effect was found between students (*B* = -0.87, *SE* = 0.033, 95% CI [-0.153, -0.022]), although the wide confidence interval indicates a low level of certainty in the model. The difference between the two measures in the variation between participants can also be seen in the EMMs of total ST and 30-min ST.

RQ2: Moderating Role of Resilience

No moderating role of resilience on the relationship between total ST and perceived stress was found (*B* = -0.005, *SE* = 0.005, *t* (550) = -0.935, *p* = 0.35, 95% CI [-0.015, -0.005]). In the same model, no significant effect of resilience was found on perceived stress (*B* = -0.09, *SE* = 0.063, 95% CI [-0.213, 0.033]). However, for the 30-min ST scale the moderation model showed that the main effect of resilience on stress was significantly negative (*B* = -0.082, *SE* = 0.042, 95% CI [-0.164, -0.001]), but there was also no significant moderating role of resilience on the relationship between ST and perceived stress (*B* = -0.002, *SE* = 0.002, *t* (752) = -1.542, *p* = 0.124, 95% CI [-0.006, 0.001]).

As a post hoc exploration of the relationship between trait resilience and perceived stress, a univariate LMM was conducted with resilience as the independent variable and perceived stress as the dependent variable. Model 4 shows that there was indeed a significant negative effect of resilience on perceived stress (*B* = -0.133, SE = 0.26, 95% CI [-0.184, -0.082]).

Table 3

Linear Mixed Models for Fixed Effects of the Variables Total Sedentary Time and Resilience on Perceived Stress

Variable	*B*	*SE*	*t*	*p*	95% CI
Model 1					
Intercept	1.857	0.248	7.479	<.001	[1.369, 2.345]
ST	0.032	0.021	1.540	.124	[-0.009, 0.072]
Model 2					
Intercept	1.727	0.552	3.130	.002	[0.638, 2.816]
PM ST	0.044	0.051	0.866	.387	[-0.056, 0.144]
PMC ST	0.029	0.022	1.309	.191	[-0.015, 0.074]
Model 3					
Intercept	4.228	1.687	2.519	.012	[0.930, 7.526]
Resilience	-0.090	0.063	-1.434	.152	[-0.213, 0.033]
ST	0.164	0.139	1.175	.241	[-0.110, 0.438]
Resilience*ST	-0.005	0.005	-0.935	.350	[-0.015, 0.005]
Model 4					
Intercept	5.756	0.697	8.257	<.001	[4.381, 7.131]
Resilience	-0.133	0.26	-5.153	<.001	[-0.184, -0.082]

Note. CI= Confidence Interval; ST = sitting time; PM = person mean; PMC = person mean centred.

Discussion

The current study aimed to investigate the relationship between ST and perceived stress in university students over time, considering the trait resilience as a potential moderator. Overall, no support was found for a relationship between daily ST and perceived stress, neither within nor between participants. However, a significant between-person association was identified when ST was measured for the past 30 minutes, indicating that differences in ST over short periods are linked to perceived stress across individuals. Further, resilience did not moderate the relationship between ST and perceived stress.

The first research question *How is the relationship between ST and perceived stress among university students over time?* revealed that there was no significant relationship between

the two variables. Both visualizations and statistical inferences supported this finding as no consistent pattern was visible over time. This contrasts with the findings of Silva et al. (2018). Considering that their study was based on a cross-sectional design and solely focused on screen-based ST, the variables may not align consistently over time leading to different results when assessed momentarily, as shown in the EMMs. On the first weekend, it appeared that total ST and perceived stress could correlate at a sample level, but this may be related to the high variation of the variables. However, perceived stress had a general tendency to be lower in the evenings and during the weekends which was not the case for sedentary time. Furthermore, the descriptives showed that perceived stress was low in the sample, which is not in line with the literature on university students in America (ACHA, 2019). This discrepancy may be related to the high resilience score in the sample, as a significant negative relationship of resilience was found with perceived stress.

Another explanation for the unexpected absence of an association between ST and perceived stress could be that the self-report nature of this study has led to unrealistic ST reports that needed to be corrected for both ST measures. Thus, more objective measurements could yield different results (Teychenne et al., 2019). However, the estimated average ST of 10.51 hours is consistent with the findings of Bertrand et al. (2021), who found an increase of ST close to eleven hours during the COVID-19 pandemic. Therefore, the lasting consequences of the pandemic, such as remote learning environments and decreased physical activity, may influence SB patterns beyond momentary stress levels (Beller et al., 2023). Thus, the ESM design of the current study suggests that perceived stress and ST of university students can be influenced by other factors that may not align consistently over time.

By further investigating the first sub-question of RQ1 *How is the within-person relationship between sedentary time and perceived stress among university students over time*? no within-person relationship between sedentary time and perceived stress was found. This finding suggests that fluctuations in an individual's ST are not related to their perceived stress levels on a daily basis. Therefore, situational factors, such as the specific context in which ST occurs, may not significantly influence perceived stress levels and ST in this population. This does not align with previous ESM studies as Diaz et al. (2018) found contextual factors, such as work-related stress, to be significantly associated with ST. The current findings suggest this may

not be the case for university students, indicating other factors may be more influential in the covariance of ST and perceived stress over time.

When investigating the second sub-question of RQ1 *How is the between-person relationship between sedentary time and perceived stress among university students?* a significant effect was found for the 30-min ST measure. This suggests that individuals with high ST may consistently report either higher or lower perceived stress compared to those with lower ST. While the correlation between the two ST measures indicates that individuals who report higher levels of ST at a short-term level also report higher levels of ST throughout the day, no significant between-person associations were found for daily ST. Therefore, the findings indicate variability in how short-term ST is associated with perceived stress across students. This outcome is particularly noteworthy given that existing literature also identified such between-person associations when measuring ST as a daily average (Diaz et al., 2018). Therefore, further research is needed to fully understand the reasons behind the observed discrepancy between short-term and daily average ST associations with perceived stress.

The second research question *To what extent does the trait resilience moderate the overall relationship between ST and perceived stress over time among university students?* revealed no significant results. Given that the perceived stress level in the sample was generally low while ST was generally high, the impact of resilience may not have been substantial. Therefore, the findings suggest that resilience does not play a moderating role in the relationship between ST and perceived stress in this population. However, as part of a post hoc analysis, a significant relationship between resilience and perceived stress was found. Individual visualizations also support this finding as a student high on resilience perceived low levels of stress and recovered more quickly from stress while the other student who was low on the trait resilience perceived higher levels of stress and recovered less quickly, which is in line with previous literature (Diehl et al., 2012). Moreover, no relationship was evident between ST and perceived stress for either student. Therefore, the findings of this study suggest that students who are less resilient may perceive more stress, while those who are more resilient may perceive less stress, irrespective of their ST.

Overall, this study shows notable strengths that may impact future research. Specifically, the longitudinal nature of the ESM design gave insights into the daily fluctuations of the variables over time (Myin-Germeys et al., 2018). The variables of perceived stress and ST

were analysed in real-life contexts for a duration of two weeks, achieving a total response rate of 83.9%. This demonstrates an excellent compliance rate, as a review by Rintala et al., (2019) has shown that ESM studies typically report compliance rates up to 79%. In addition, the SNRS-11 exhibited strong psychometric qualities, making it possible to draw reliable conclusions. Furthermore, visualizing the results of the ESM demonstrated that the relationship between perceived stress and total ST may be time-dependent and may vary between students, insights that were not apparent from statistical inferences alone. Moreover, investigating ST for the last 30 minutes and for the past day enables a more comprehensive evaluation of ST by capturing both immediate associations with perceived stress and overall ST patterns over the entire day. By combining both measures, the study offers a nuanced understanding of how ST is associated with perceived stress.

However, there were also some limitations in the study design. The split-half reliability of the PAST-U was weak. Additionally, the reliability of the 30-min ST scale was also weak, indicating a higher inconsistency in the responses of the participants. A reason for this inconsistency could be that a duration of two weeks may have led to increased participant burden, potentially leading to inaccurate responses that needed correction (Myin-Germeys et al., 2018). Regarding the weak reliability, making inferences with the results of both ST measures should be taken with caution.

As a result, future research could benefit from further investigating the difference between short-term ST and measuring ST as a daily average, potentially considering perceived stress as a daily average in addition to short-term perceived stress. Additionally, incorporating objective measures, particularly for ST, could yield more accurate results (Teychenne et al., 2019). Furthermore, incorporating a break between the times of measurement when conducting an ESM study could alleviate participant burden without reducing the overall duration of data collection (Diaz et al., 2018). Based on the finding of between-person associations, it is also essential for future research to consider factors other than resilience, which could influence the relationship between ST and perceived stress, potentially resulting in a better understanding of SB and perceived stress in university students.

All in all, ST was not associated with perceived stress in the current sample. However, the study's longitudinal design underlines that the association between these variables is more pronounced when comparing short-term ST and perceived stress across different individuals

rather than within the same individual over time. Moreover, the findings highlight that resilience may reduce perceived stress levels in university students, regardless of their ST. Thus, the relationship between ST and perceived stress is complex and may be influenced by factors other than resilience, which differ between individuals. These insights provide a basis for future research to identify such factors and promote tailored educational programs in universities to reduce the students' perceived stress, ultimately enhancing their mental health and well-being.

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Appendix A

Baseline Questionnaire

Demographics

1. What is your gender?
    a. Male
    b. Female
    c. Other
    d. Prefer not to say
2. What is your nationality?
    a. Dutch
    b. German
    c. Other, please specify:
3. What is your current occupation?
    a. Enrolled at a university
    b. Enrolled at another higher education institution (HBO, Fachhochschule)
    c. Other, please specify:
4. Are you able to stand for 30 minutes at a time without any support?
    a. Yes
    b. No
5. If you are participating via Sona, please indicate your SONA ID: _____

CD-RISC-10

1. I am able to adapt to change.
2. I can deal with whatever comes my way.
3. I try to see the humorous side of problems.
4. Coping with stress can strengthen me.
5. I tend to bounce back after illness or hardship.
6. I can achieve goals despite obstacles.
7. I can stay focused under pressure.
8. I am not easily discouraged by failure.
9. I think of myself as strong person.
10. I can handle unpleasant feelings.

Likert scale, with options ranging from "strongly disagree" to "strongly agree."

Appendix B

Sedentary Time: PAST-U

1. 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.)
2. How long were you sitting for transportation/travelling yesterday? (Include sitting and waiting for transport. Do not include any time you were standing up while travelling or waiting.)
3. 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.)
4. How long were you sitting or lying down while reading during your leisure time yesterday? (Include reading in bed, but do not include reading for work or study.)
5. How much time did you spend sitting down for eating and drinking yesterday?
6. How much time did you spend yesterday sitting down to socialise with friends or family, regardless of location? (Include at university, at home, or in a public place, on the telephone, etc.)
7. How much time did you spend yesterday sitting down to socialise with friends or family, regardless of location? (Include at university, at home, or in a public place, on the telephone, etc.)

Appendix C

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 anonymized 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:

r.a.s.kruk@student.utwente.nl
p.h.naber@student.utwente.nl
i.a.solan@student.utwente.nl
e.g.avanisian@student.utwente.nl
m.o.tebarth@student.utwente.nl
Supervisor: g.schaap@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 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 D

Analysis of 30-min ST scale

Figure D1

Estimated Marginal Means of 30-min ST and perceived Stress over 42 Measurement Points

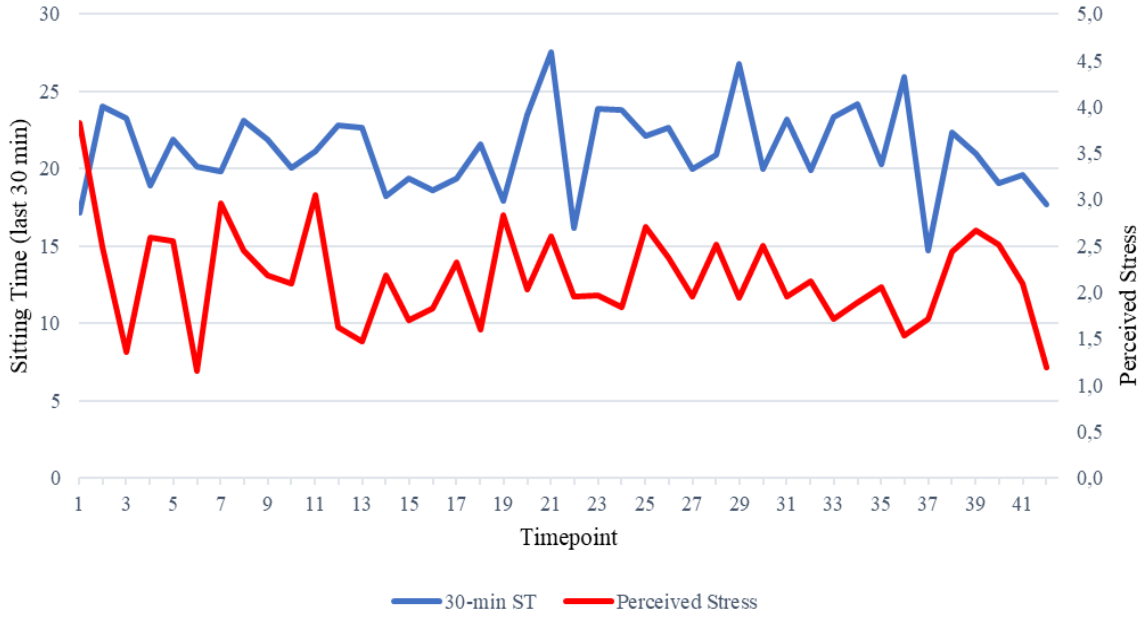

Figure D2

Estimated Marginal Means of 30-min ST and perceived Stress for all 25 Participants

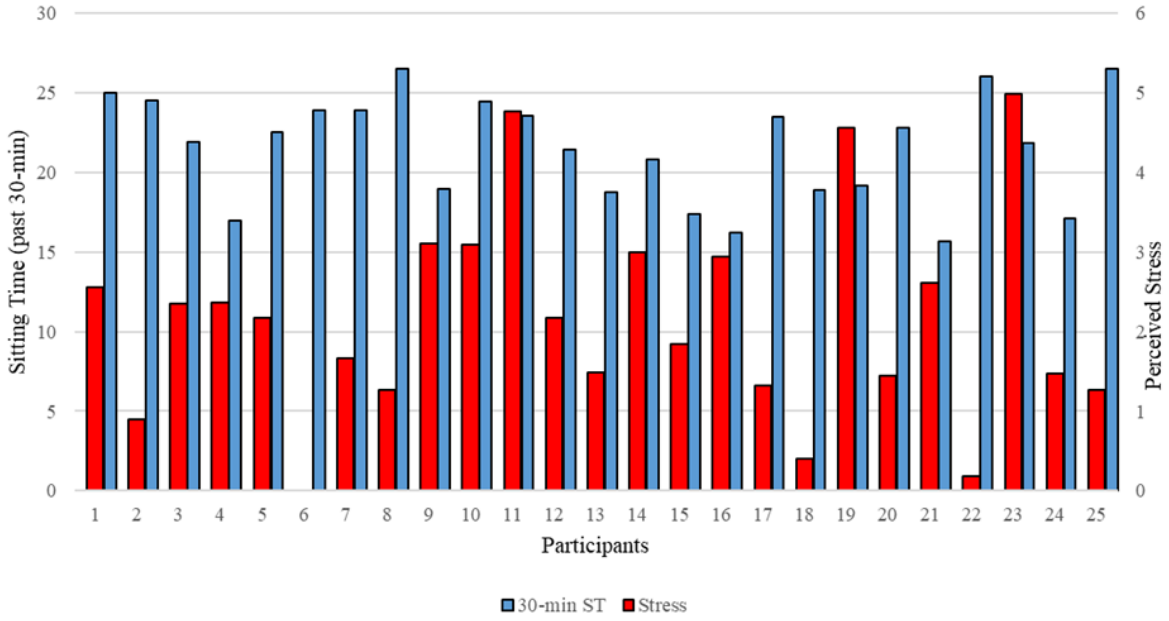

Figure D3

Total Sitting time and perceived stress for participant 23

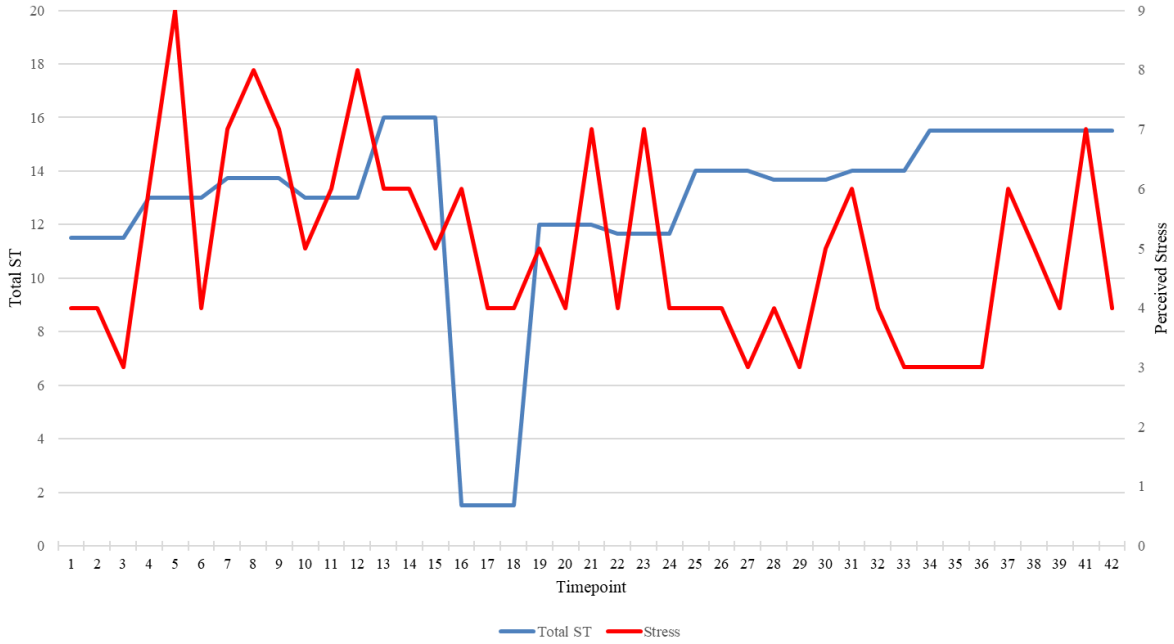

Figure D4

Total Sitting Time and Perceived Stress for Participant 24

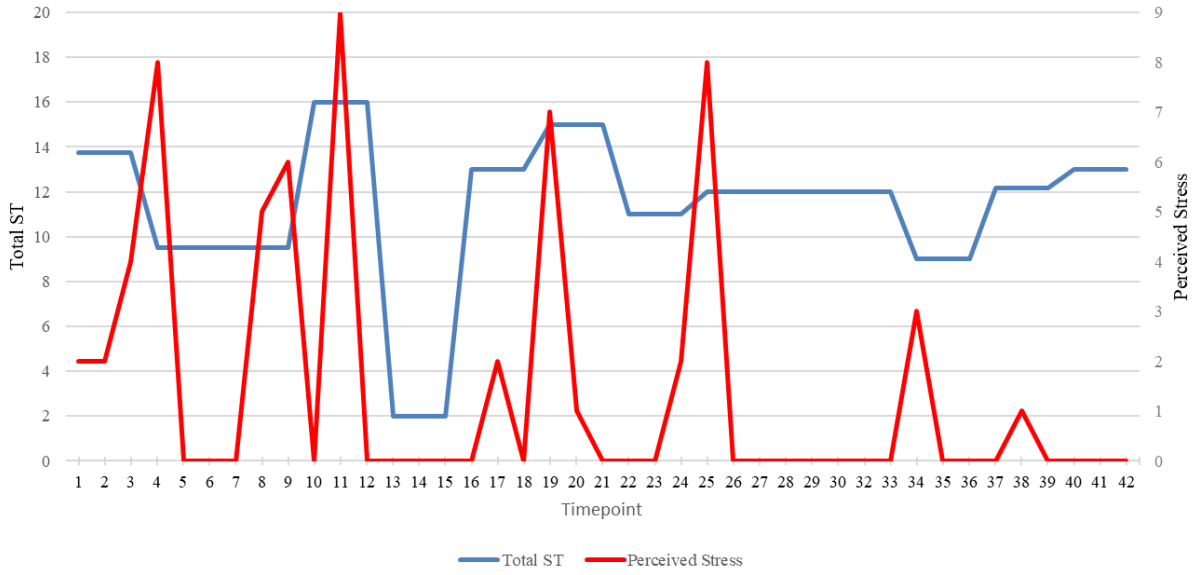

Table D1

Linear Mixed Models for Fixed Effects of the Variables 30-min Sedentary Time and Resilience on Perceived Stress

Variable	*B*	*SE*	*t*	*p*	95% CI
Model 1					
Intercept	2.066	0.179	11.561	<.001	[1.715, 2.417]
ST	0.006	0.007	0.965	.335	[-0.007, 0.019]
Model 2					
Intercept	4.070	0.715	5.696	<.001	[2.660, 5.479]
PM ST	-0.087	0.033	-2.645	.009	[-0.153, -0.022]
PMC ST	0.010	0.007	1.537	.125	[-0.003, 0.024]
Model 3					
Intercept	4.305	1.127	3.818	<.001	[2.091, 6.518]
Resilience	-0.082	0.042	-1,985	.048	[-0.164, -0.001]
ST	0.070	0.043	1,623	.105	[-0.015, 0.155]
Resilience*ST	-0.002	0.002	-1,542	.124	[-0.006, 0.001]

Note. CI= Confidence Interval; ST = sitting time; PM = person mean; PMC = person mean centred.