Stressed out from Sitting? - Exploring the Relationship Between Sedentary Behaviour and State Perceived Psychological Stress in University Students Using Experience Sampling

Bachelor Thesis

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Abstract

Background: Nowadays, our society, especially university students, spends a significant time sedentary, which can lead to serious physical and mental health consequences. Previous research suggests mentally passive sedentary time and state stress to be positively and mentally active sedentary time and state stress to be negatively associated. Physical activity might moderate these relationships. Hence, the current study aimed to explore the relationship between mentally active or passive sedentary time and state perceived psychological stress within university students over time, and the role of physical activity as a moderator.

Method: An Experience Sampling study was conducted to explore the relationships. The app Ethica was used to analyse 37 participants' (female: 73%, age: M = 20.64, SD = 2.13) sedentary time, physical activity and state stress data collected through three daily questionnaires over the span of one week. Linear Mixed Models were used for analysis.

Results: A significant negative relationship was observed between passive sedentary time and stress (B = -0.110, SE = .052, F(248.846,612.059) = 4.510, p = .034). However, no significant relationships for total (p = .329) or active (p = .689) sedentary time with stress were found. Physical activity was not found to be moderating the relationship for total (p = .714), active (p = .691), or passive (p = .850) sedentary time and stress.

Discussion: The current study's results go against expectations set by previous research on the topic of sedentary behaviour. Mentally passive sedentary time was found to reduce state perceived psychological stress, which was the opposite direction as previously expected. Total and active sedentary time were not significantly associated with stress. Future research should investigate the latter relationship further to gain deeper knowledge and clarify the actual relationship.

Keywords: sedentary behaviour, sedentary time, mental activity, state stress, physical activity, moderate-to-vigorous physical activity, experience sampling method

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Introduction

As extensive sitting has become an increasingly important part of our lives over the last decades, sedentary behaviour has turned into a population-wide problem with severe negative health outcomes (Owen et al., 2010; O'Donoghue et al., 2016). The total time spent sedentary varies between populations, but research suggests that adults from high-income countries usually spend around eight to 12 hours a day sitting, constituting the great majority of their days (Matthews et al., 2008; Hagstromer et al., 2015). Other studies suggest an amount of around 75% of waking hours and 90% of leisure time spent sedentary for high-income adults (Diaz et al., 2017; Healy et al., 2011). Since the outbreak of COVID-19, people have spent even less time being active and more time sitting in front of a screen (e.g. their laptop or smartphone), further decreasing their mental health. The pandemic has, thus, emphasised the problem of prolonged sitting worldwide (Meyer et al., 2020). University students specifically spend an increasing amount of time sitting, especially since the pandemic (Castro et al., 2020; Bertrand et al., 2021). This prolonged sitting has been found to have negative health consequences, including increased stress levels (O'Donoghue et al., 2016). Therefore, the goal of this study was to explore the relationship between sitting time and perceived psychological stress among university students.

Defining Sedentary Behaviour

Sedentary behaviour compasses behaviours which are mainly characterised by a sitting or reclining posture, without being otherwise active. It is associated with low levels of metabolic energy expenditure (≤1.5 metabolic equivalents; Tremblay et al., 2017). Typical exemplary sedentary behaviours include tv viewing, computer use and driving (Owen et al., 2010; Hallgren, et al., 2020; O'Donoghue et al., 2016). Recent research suggests that it is of great importance to look at the different contexts in which sitting occurs, as they give insight into how people engage in sedentary behaviour. These contexts can be categorised into four main categories, as proposed by Owen et al.'s (2010) socio ecological model of sedentary behaviour. The model distinguishes between the domains of occupation, transportation, leisure time and the domestic context (i.e. an individuals' household). The domestic context is associated with the greatest amount of risks that sitting has on individuals' health (Hallgren et al., 2020).

Extensive time spent sitting has been found to have negative effects on both physical as well as mental health have been found for individuals who spent extensive time sitting. These include health consequences independent of the ones associated with general physical inactivity. The latter is distinct from prolonged sitting since individuals can be sufficiently physically active but still spend too much time sedentary (Owen et al., 2010; Bakker et al., 2020; Tremblay et al., 2017). The most common physical health consequences of sedentary behaviour include increased risk of cardiovascular disease, type 2 diabetes, cancer, obesity, pulmonary disease and all-cause mortality (Dempsey et al., 2016; Young et al., 2016; Saunders et al., 2020; O'Donoghue et al., 2016). However, sedentariness poses not only a risk to physical but also mental health, as it has been linked to an increase in depressive symptoms, psychological stress, anxiety and overall worse mental health (Hallgren et al., 2020; O'Donoghue et al., 2016; Hamer et al., 2014; Bélair et al., 2018; Rodriguez-Ayllon et al., 2019).

Defining Mental Activity

Sedentary behaviour has been distinguished by the amount of mental activity used while engaging in specific sitting activities. Mentally active behaviours are characterised by requiring higher cognitive efforts and attention, including reading or working, whereas mentally passive behaviours require far less, for instance watching tv or listening to music. Depending on the mental activity used while being sedentary, its associations with mental health may be different. High mental activity is generally associated with positive and preventative effects on mental health, whereas mental passivity seems to be affecting it negatively, as suggested by longitudinal studies on sedentary behaviour and depression (Hallgren et al., 2020; Hallgren et al., 2018).

This has been explained by suggesting that mentally active sedentary tasks are usually engaging and rewarding (Hallgren et al., 2018), whereas mentally passive sedentary tasks are often characterised by social isolation and removing individuals from opportunities to interact with others and reaching out for social support (Hallgren et al., 2020). Hence, it is important to not only look at an individual's sitting time, but also what specific activities they perform while sedentary. Up until this point, studies taking mental activity into account have primarily focused on depression as a mental health outcome (Hallgren et al., 2018; Hallgren et al., 2020). The association between sedentary behaviour and psychological stress has not yet been researched in

the context of mental activity so far. Thus, further research is needed to find out if mentally active and passive sedentary behaviour influence stress in similar ways as depression.

Defining Psychological Stress

Psychological stress can be considered a 'modern day hidden epidemic' (Kalia, 2002), as its prevalence is high and its impact on health rises continuously (Teychenne et al., 2019). Generally, stress is a negative emotional state typically associated with feelings of nervousness, tension and strain. These can manifest themselves as worries, fatigue or feelings of inability to cope (Teychenne et al., 2019). Stress is typically experienced when individuals are confronted with situations in which they feel taxed or like their abilities to manage are exceeded (Carver et al., 2010). According to the American Psychological Association (2019a), more than three-quarters of adults in the US report physical and emotional symptoms of stress, highlighting the high prevalence of stress in people's everyday lives.

The origin of stress is an evolutionary one, as it stems from the body's automatic fight or flight response to life-threatening situations. The body is then flooded with hormones, which increase one's heart rate, blood pressure and boost energy. Stress is an important factor in survival, as it temporarily improves mental and physiological functioning (Mason, 2013; American Psychological Association, 2013). Nowadays, we are usually not experiencing stress due to our lives being threatened, but rather due to the daily life stressors such as meeting deadlines or paying bills. Nevertheless, the fight or flight response is activated and can have detrimental health consequences (American Psychological Association, 2013).

Stress not only worsens already existing health problems, such as chronic headaches, but can even cause disease through the unhealthy coping mechanisms individuals develop (American Psychological Association, 2013). Both acute and chronic high levels of stress have been associated with severe negative health outcomes. Chronic stress is linked to physical health problems such as increased risk of cardiovascular disease, long-term disability, memory problems, cognitive impairment, obesity and a weakened immune system. Besides, on a psychological level, chronic stress may lead to irritability, fatigue, insomnia, depression and anxiety (Bergdahl & Bergdahl, 2002; Kizhakkeveettil et al., 2017; Dedele et al., 2019; Teychenne et al., 2019; American Psychological Association, 2019b). But also acute stress has its impact on people, potentially leading to long-term consequences on the brain as well as cardiovascular, metabolic,

immune systems (Dedele et al., 2019). The American Psychological Association (2013) distinguishes between short-lived minor acute stress and major acute stress. While the former might manifest itself in a slight stomach ache, the latter can have far more severe effects. Sudden emotional stresses can trigger heart attacks, arrhythmias or even death (American Psychological Association, 2013). Lastly, a link has been found between stress and the six leading causes of death, namely heart disease, accidents, cancer, liver disease, lung ailments, and suicide (Schneiderman et al., 2005).

Sedentary Behaviour and Psychological Stress

Research has shown that stress and other mental health issues such as depression and anxiety, could potentially be reduced by healthy lifestyle behaviours, for instance a healthy diet and increased physical activity. However, to this day, there is little research on the relationship between sedentary behaviour and stress. As sedentary behaviour has been associated with negative mental health outcomes (Teychenne et al., 2019), it is plausible to assume a link between sedentary behaviour and stress. Several studies found associations between psychological stress and sedentary behaviour, suggesting higher levels of stress in individuals who sit longer. However, most studies made use of cross-sectional study designs and did not include mental activity or the different contexts of sedentary behaviour in their research (Mouchacca et al., 2013; Felez-Nobrega et al., 2020), showing a need for further research.

Physical Activity

Another crucial aspect related to sedentary behaviour is physical activity, which can be defined as ‘any bodily movement produced by skeletal muscle that results in energy expenditure’ (Caspersen et al., 1985, p.126). It is typically classified into four levels, namely not active (i.e. resting rate) (MET 1), light intensity (MET <3), moderate intensity (MET 3-6) and vigorous intensity (MET ≥6) (Romeo et al., 2010; Mccomb et al., 2014). Examples of the three active categories are doing household chores, brisk walking, and going for a run (Piercy et al., 2018). Further, Warburton and Bredin (2017) proposed that there is no certain threshold of exercising that should be reached, but that “simply moving more” (p.4) could already benefit one’s health.

Research on physical activity and its impact on depression has shown that the risk of depression is reduced through regular physical activity (Zhai et al., 2015). In another study by

Piercy et al. (2018), physical activity has been found to improve quality of life, reduce anxiety, and lower the risk for depression. Furthermore, moderate-to-vigorous physical activity has been found to attenuate or even eliminate increased mortality risks of sedentary behaviour (Ekelund et al., 2016). The research by Ekelund et al. (2016), thus, showed that the two constructs seem to interact to influence people's health, specifically their mortality. Since moderate-to-vigorous physical activity has the potential to reduce or eliminate negative effects of prolonged sitting, it is of importance to investigate its effect as a potential moderator of the relationship between sedentary behaviour and psychological stress.

Sedentary Behaviour and Stress in University Students

University students form a sub-group with both high sedentary times and high stress levels (Castro et al., 2020; Hamaideh, 2011), making them a target group of interest for investigating the association between sedentary behaviour and psychological stress, moderated by physical activity. University student's overall sitting rates have increased significantly over the past decade. Nowadays, their daily sitting time is even higher than that of a desk-based working adult who spends around 9.4 hours sedentary per day (Rosenberg et al., 2010; Moulin and Irwin, 2017). Other research on student's sedentariness has found averages of sedentary time ranging from seven to almost 12 hours daily (Castro et al., 2020; Keating et al., 2020; Moulin and Irwin, 2017). During the COVID-19 outbreak, these durations are likely to have risen, as Bertrand et al. (2021) suggest a significant increase in sitting time alongside decreased levels of physical activity. Students, hence, form a population sub-group which is especially sedentary, even more than other young adults (Castro et al., 2020; Bertrand et al., 2021). Although the increasing sitting time is a worldwide problem affecting all age-groups, university students are particularly vulnerable to this phenomenon (Matusiak-Wieczorek et al., 2020).

Students being especially prone to high sitting rates can be explained partly by their typical activities, such as attending lectures or studying, being predominantly sedentary (Keating et al., 2020). However, these activities are also associated with high mental activity, as suggested by Hallgren et al. (2020). Besides their study time, which constitutes the greatest number of hours sitting, leisure time in front of a screen is keeping university students sedentary most. According to research, nearly 48% of their leisure time is spent in front of a computer screen (Caromano et al., 2015).

The international concern for students' mental health as well as the consequences of unrecognised and untreated disorders has been rising (Stallman, 2010). When it comes to both short-term as well as continuous stress, university students constitute a frequently exposed group, partly due to the stressful nature of the expectations for and roles of university students (Hamaideh, 2011). The stressors most characteristic for students' lives include the transition to university, academic demands, pressure to get good grades, finding friends and building peer relationships, new living situations, financial problems, and changes in the relationships with friends and family, with the highest group of stressors being self-imposed (Hamaideh, 2011; Hartley, 2011; Pidgeon et al., 2014).

In students specifically, these high stress levels may increase substance abuse, smoking and other negative habits concerning health (Carpenter et al., 2002), as well as harm students' academic performance and increase the likelihood of dropping out of university (Shields, 2001). Further, severe stress has the potential to cause other mental health problems in students, such as depression, burnout and suicidal thoughts (Dahlin et al., 2005; Tyssen et al., 2001). Research suggests that 50% of all students experience significant stress, which manifests itself in either depression or anxiety (Regehr et al., 2013). Due to the extensive research suggesting a high frequency of sedentary behaviour as well as stress in students, it is crucial to investigate further on this particular at-risk group.

Experience Sampling Method

Most previous research exploring sedentary behaviour has made use of cross-sectional study designs, which are taking a global and retrospective approach, differentiating them from Experience Sampling Method (ESM) studies (Myin-Germeys et al., 2018). Important limitations of cross-sectional designs include recollection error, low response rates and self-selection bias (Wright, 2017). Besides, they cannot investigate temporal associations, as data is only recorded once. While a cross-sectional study cannot rule out reverse causality, ESM studies can be used to at least indicate directionality (Owen et al, 2010; Hallgren et al., 2020; Sedgwick, 2014).

An ESM study design, on the other hand, can resolve some of the above mentioned limitations. This approach became more and more popular with the improvements of technology, specifically smartphones (Conner & Lehman, 2012; Van Berkel, et al., 2017). ESM is a study design that investigates activities or emotions over a longer time-frame instead of a single point in

time, thus, providing more understanding of contingencies of behaviour. Constructs are measured in the participants' natural environments and, hence, ecological validity is increased because of a greater generalizability of findings (Scollon et al., 2003; Van Berkel et al., 2017). This makes it an optimal design for natural settings without the experimenter's influence (Conner and Lehman, 2012). Further, within-person associations can be investigated, which allows for insights into state conceptions of behaviours and emotions rather than simple trait conceptions (Scollon et al., 2003; Conner and Lehman, 2012). This may be particularly relevant for the current studies' constructs, namely sitting time, psychological stress and moderate-to-vigorous physical activity. These are constructs which can vary greatly from day to day, especially considering that there may be significant differences between workdays and the weekend. That is why they should be considered as state rather than trait measures. Lastly, pitfalls such as memory biases can be reduced because there is a rather short time lag between signal and the participant's response (Scollon et al., 2003).

Current Study

The current study used ESM to explore the relationship between sitting time, mental activity and state perceived psychological stress in university students. Besides, the role of moderate-to-vigorous physical activity as a potential moderator was investigated (see Figures 1 and 2). The current study tries to answer several research questions. The first question deals with the relation of mentally active sedentary behaviour and perceived psychological stress: *"What is the relationship between daily mentally active sedentary time and daily state perceived psychological stress within university students over time?"* The second question, accordingly, deals with the relation of mentally passive sedentary behaviour and perceived psychological stress: *"What is the relationship between daily mentally passive sedentary time and daily state perceived psychological stress within university students over time?"* The third question includes the third variable, physical activity: *"How is the relationship between daily sedentary time and daily state perceived psychological stress moderated by daily moderate-to-vigorous physical activity?"*.

Based on the review of previous research on sedentary behaviour, some expectations were posed. In accordance with research emphasising negative mental health consequences of sedentariness (Hallgren et al., 2020; O'Donoghue et al., 2016; Hamer et al., 2014; Bélair et al., 2018; Rodriguez-Ayllon et al., 2019), it is expected that participants' stress will increase the more total sedentary time they report. As suggested by Hallgren et al. (2018), mentally active tasks are

expected to decrease participant's state perceived stress, whereas mentally passive tasks are expected to increase it. Lastly, the research by Ekelund et al. (2016) evokes the expectation that moderate-to-vigorous physical activity moderates the relationship by strengthening the association between mentally active sitting time and state stress (see Figure 1) and decreasing the association between mentally passive sitting time and state stress (see Figure 2).

Figure 1

The Expected Effects of Daily Mentally Active Sedentary Time and Daily Moderate-to-Vigorous Physical Activity on Daily Psychological Stress

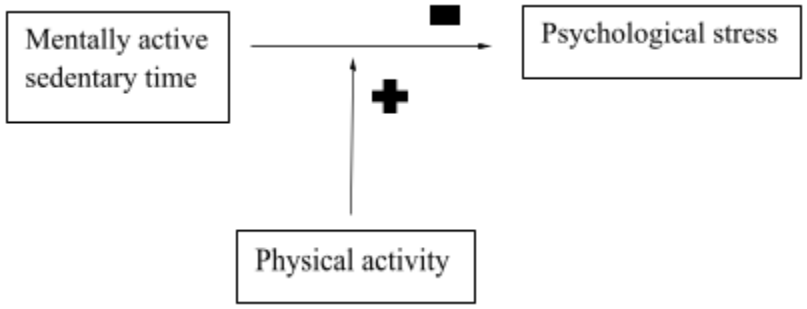
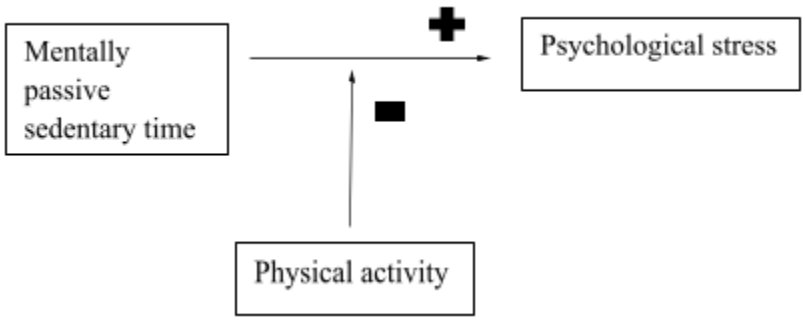


Figure 2

The Expected Effects of Daily Mentally Passive Sedentary Time and Daily Moderate-to-Vigorous Physical Activity on Daily Psychological Stress



Methods

Design

The present study was part of a broad research project about the topics of sedentary behaviour and mental health using ESM. To determine sampling frequency and duration, other scientific studies and Bachelor theses were consulted. The data collection took place for nine days, from 23rd November to 1st December 2021. According to Conner and Lehman (2012), the typical duration for studies involving multiple reports per day is between three days and three weeks. The goal of this study was to assess the chosen constructs over the span of one week, with the two additional days being necessary due to baseline and retrospective measures. Difficulties such as participant burden, participant retention and too much missing data are frequently caused by longer study durations (Van Berkel et al., 2017; Conner and Lehman, 2012). Ethical approval was obtained by the Ethics Committee at the University of Twente (case number: 211236). For the joint data collection several different items were used in the questionnaires, which are not relevant for answering this study's research questions.

The questionnaires were created and data was collected using the Ethica website (https://ethicadata.com/) and app. Ethica enables researchers to set up and conduct their ESM study via participants' smartphones or other mobile devices, notifying participants via channels they pay most attention to and, thus, maximising response rates. After finishing the initial design of the study, a pilot test was conducted among the four undergraduate researchers and four other individuals from their social environment. This was done to ensure the best understanding and usability for participants, meaning that possible mistakes or unclear elements were revised. For example, the interval of the morning questionnaire was extended to 5 hours (12am), as participants gave the feedback that it was too easy to miss the questionnaire if it already expired after three hours (10am).

The type of sampling used included fixed sampling for the morning questionnaires and random sampling with fixed time intervals for the afternoon and evening questionnaires. With a fixed sampling schedule, participants are completing questionnaires at equal time intervals, for instance every four hours. With a random sampling schedule questionnaires are sent out at random intervals within random blocks, which ensure that time is sampled evenly. The latter approach has the advantage of decreasing reactivity and allowing for time budgets, meaning that estimates of

average time that people spend in specific contexts can be provided (Myin-Germeys et al., 2018; Conner and Lehman, 2012).

Every participant started the study on the same day and received a total number of 24 questionnaires. In order to get an extensive picture, the constructs were measured at fixed and random time points over the day (see Table 1). In this study, sitting time and physical activity of the participant's previous day were measured in the morning, with a time interval of five hours from 7am to 12am. The first notification was sent at a fixed time directly at the start of the time interval (7am), with two additional reminders (9am and 11am). The expiry time was at 12am. The construct of psychological stress was measured in the morning, afternoon and evening. For the afternoon and evening measures of psychological stress, the first notification was sent at random times within the fixed intervals of 1pm to 3pm for the afternoon questionnaire and 7pm to 9pm for the evening questionnaire. The expiry times were set, 4pm for the afternoon questionnaire and 10pm for the evening questionnaire. The baseline questionnaire and informed consent form had no expiry time, participants were free to fill them out at any time throughout the data collection period. The participants who had not given their consent by the end of the study were excluded from the data set.

Table 1

Study Schedule for all Days with Relevant Variables, Points in Time, Reminders, and Expiry Times per Questionnaire

Day	Questionnaires	Variables	Time	Reminders	Expiry time
23rd Nov (once)	Baseline questionnaire	Demographics	Fixed (directly after registration in Ethica)	No	No
24th Nov (once)	First morning questionnaire	Stress	Fixed (7am)	Two (9 and 11am)	Yes (12am)
25th - 30th Nov (six days)	Morning questionnaire	Stress, ST and PA of previous day	Fixed (7am)	Two (9 and 11am)	Yes (12am)
24th - 30th Nov (seven days)	Afternoon questionnaire	Stress	Random (between 1 and 3pm)	One (30 minutes after first notification)	Yes (4pm)
24th - 30th Nov (seven days)	Evening questionnaire	Stress	Random (between 7 and 9pm)	One (30 minutes after first notification)	Yes (10pm)
1st Dec (once)	Final morning questionnaire	ST and PA of previous day	Fixed (7am)	Two (9 and 11am)	Yes (12am)

Note. Abbreviations: PA = physical activity, ST = sedentary time.

Participants

In terms of recruitment, the sampling method used was non-probability convenience sampling. Individuals from the researchers' social environments were asked if they wanted to participate and the study was published on the Sona System for students to sign up. This had the advantage of simplicity because there are no strict guidelines or inclusion criteria for the selection of participants. Further, the data collection could be facilitated in a short time and with the least financial effort (Business research methodology, n.d).

The participants had to meet some previously defined inclusion criteria to take part in the present research. They had to be at least 18 years old, speak English proficiently, be students at a university or university of applied science, and own a smartphone or similar device to download and use the app Ethica. The study was aimed to have a similar sample size as suggested by Van Berkel et al. (2017), who argued that a majority of the existing ESM studies used small sample sizes, with an estimated median of 19 participants. Therefore, the goal was to have at least 19 participants.

Materials

Throughout the whole study, different types of questionnaires were provided, including one baseline questionnaire (see Appendix A), as well as different daily questionnaires (see Appendices B and C). The baseline questionnaire collected information on the participants' demographics, asking for their gender, age, nationality and study programme, and it asked participants whether they had a suspected or diagnosed mental disorder and whether they had a condition restricting their physical activity. The data of participants who answered the items concerning the existence of a mental disorder or a condition restricting physical activity with 'yes' was compared with the data of the ones who answered 'no' by skimming through the data set. This was done to check if the group with a mental disorder or restricted physical activity answered differently in terms of their stress and physical activity than the other participants. As no major differences in mood or physical activity were observed, these items were not used as an exclusion criterion. Lastly, the daily questionnaires measured sitting time, perceived psychological stress, physical activity and other constructs irrelevant to this study, such as anxiety.

Measurements

Sitting time was measured using a modified form of the Past-day Adults' Sedentary Time-University (PAST-U) questionnaire (Clark et al., 2016), which asks participants in nine questions about their time spent sitting or lying down in different activities during the previous day. It was derived from the PAST questionnaire used by Clark et al. (2013) and modified to fit a university population. The scores of the different behaviours/domains were later summed to derive a total score. The PAST-U has shown to have acceptable validity on a group level in comparison to the data collected with an activPAL device, whereas the estimates at an individual level were poor. This suggests a greater appropriateness of the scale in large-scale studies (Clark et al., 2013). In the PAST-U, participants were asked to indicate an estimated amount of hours and minutes they spend sedentary for a particular task/domain, namely study, work, transport, tv viewing, computer/internet/electronic games, reading, eating, socialising, and "other purposes". An example of an item used is: *"How long were you sitting while studying yesterday? (include the time at university, during lectures, tutorials, meetings, group discussions, self-study, study from home, etc.)"* (Clark et al., 2016). The categorization of activities/domains into mentally active and mentally passive were adapted from previous research on sedentary behaviour and mental activity by Hallgren et al. (2018) (see Table 2). Besides, several items were added to the questionnaire to make it appropriate for the current study. This was the case as Hallgren et al.'s (2018) framework could not be applied to some of the original items because they were unclear regarding their mental activity. Hence, the ambiguous items, such as sitting for transport, were divided into two items to allow for the construct of mental activity to be applied correctly. Further, an additional item measuring sedentary time spent during creative activities was added on request of the pilot study participants, who stated that they spend an extensive amount of time on creative hobbies such as making music. The reliability of the revised items was assessed by means of split-half reliability analyses with a Spearman-Rho coefficient.

Table 2

Revised PAST-U Items Sorted into Hallgren et al.'s (2018) Categories of Mentally Active and Mentally Passive Sedentary Behaviour

Mentally active	Mentally passive
Sitting for study	Sitting for transport not driving yourself
Sitting for work	Sitting for TV/DVD viewing
Sitting for transport driving yourself	Sitting for passive computer use
Sitting for gaming on the TV	Sitting for eating
Sitting for active computer use	
Sitting for reading	
Sitting for socialising	
Sitting for creative activities	

The construct of psychological stress was measured with a single-item scale, namely the Stress numerical rating scale-11 (SNRS-11), which was first developed by Karvounides et al. (2016). A single-item scale was decided on to avoid unnecessary participant burden caused by lengthy assessment. The SNRS-11 was modelled after a single item assessment for pain, the NRS-11, a commonly used and validated survey (Karvounides et al., 2016). With three different studies, the developers tested the item, achieving satisfactory results. The SNRS-11 was shown to have moderate to strong construct validity, moderate concurrent validity and good discriminate and convergent validity (Karvounides et al., 2016). Furthermore, the SNRS-11 is a commonly used measurement in ESM studies, for example in Bachelor and Master theses of the University of Twente (Buschmeyer, 2020; Wagener, 2021; Böggemann, 2020). Like in the research by Karvounides et al. (2016), a scale from 0 to 10 was used to assess participants' stress daily, asking them to indicate which number best described their current stress level: *"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?" Indicating a high score was, thus, associated with feeling very stressed out, whereas achieving a low score was associated with feeling relaxed.

The construct of moderate-to-vigorous physical activity was measured with two items taken from the short form of the International Physical Activity Questionnaire (IPAQ-SF), which originally entailed seven questions and involves seven-day recall of physical activity. It is used as a standardised measure to estimate physical activity of different countries and socio-cultural contexts (Maddison et al., 2007). In previous research, Craig et al. (2003) have suggested both versions of the IPAQ to be reliable and showing acceptable criterion validity by means of data from 12 different countries. Two items were chosen from the IPAQ-SF. However, these items needed to be adjusted to ask about the previous day instead of the last week for this study. Besides, examples of both vigorous and moderate physical activities were added, so the participants had a better understanding of what these activities levels entail. The examples were taken from two other items of the original IPAQ-SF. The adjusted items decided on were the following: *"How much time in total did you spend doing vigorous physical activity yesterday (e.g. heavy lifting, digging, aerobics, or fast bicycling)?"* and *"How much time in total did you spend doing moderate physical activity yesterday (e.g. carrying light loads, bicycling at a regular pace, or doubles tennis)?"* Participants were asked to give their answers in minutes.

Procedure

Before the start of the study, all participants received general information about the study and its purpose either by the researchers themselves or through the Sona System, as well as instructions on how to download the Ethica app and sign up with the registration code. At the official start of the study, every participant received a digital informed consent form (see Appendix D) through Ethica, which they needed to agree with to partake. This form notified them that participation in the research was voluntary and that they were allowed to withdraw from the study at any time, without needing to provide a reason. Besides, their data would be anonymised and handled confidentially. They were also warned to reconsider their participation if they were sensitive to the topics of the research, for instance if they had previously received an official diagnosis of a mental disorder. By actively consenting to the study's conditions, participants agreed to continue their participation. Participants also received the baseline questionnaire at the same time as the informed consent form. It included an assessment of the participants' demographics as well as trait

personality measures irrelevant to the current study. Afterwards, they got notified that this was all they needed to do for the first day and that they would receive the daily questionnaires from the next day onwards.

Within the following days, participants received their three questionnaires daily through Ethica (see Table 1). The morning questionnaire (see Appendix B) included the items measuring sedentary time and moderate-to-vigorous physical activity of the previous day and the items measuring psychological stress. The afternoon and evening questionnaires (see Appendix C) were identical except for one added construct in the morning, both measuring psychological stress and other psychological constructs irrelevant to the current study. Reminders for the morning questionnaire were sent at 9am and 11am. The reminders for the afternoon and evening questionnaire were sent an hour before the expiry times. The expiry times were 12am for the morning-, 4pm for the afternoon-, and 10pm for the evening questionnaire.

After seven days of receiving the daily questionnaires, the ninth and final day of assessment only required the participants to fill out a final morning questionnaire, which dealt with sedentary time and physical activity of the previous day. Afterwards, participants were finished with the study. At the end of the data collection, participants received a last information page with a short thank you for their participation from all involved researchers (see Appendix E).

Data Analysis

The collected data was imported into SPSS (version 26) in long format. First, the separate Ethica surveys were merged together in SPSS to create one comprehensive dataset. Next, the dataset was cleaned: variables were renamed or computed, and all participants who did not have sufficient response rates were excluded. The cut-off point was chosen based on the average response rate of ESM studies, namely 69.9% (Van Berkel et al., 2017). It was, thus, decided that all participants with a response rate of less than 70% should be excluded. In addition, most participants (>66%) had a response rate above 70%. Besides, the participants who did not fill in the informed consent form or baseline questionnaire were excluded as well.

The variable for total sitting time was computed by adding up the measurements of all PAST-U items. Two other variables for active and passive sedentary time were computed by adding up the measurements of the corresponding mentally active or passive PAST-U items. To give comprehensible results in the report, three new variables in hours were computed by dividing

each of the sedentary time variables by 60. Lastly, a variable for total physical activity in hours was computed by adding up the two separate variables.

After preparing the data set, the participants' demographics were analysed. For this, descriptive statistics were run for gender, age, nationality, study programme, the existence of a mental health diagnosis, and the existence of a condition restricting physical activity. These included percentages, minimums and maximums, means and standard deviations.

Further, the internal reliability was assessed for the PAST-U, SNRS-11 and IPAQ-SF items. This was done using half-split reliability analyses with a Spearman-Rho coefficient (Csikszentmihalyi et al., 2014). For this, the data set was first changed into wide format. The 21 measurements of each test were split into two groups, one consisting of points one to 11 and one of points 12 to 21, and combined into new variables. Then the means for both variables were computed. Afterwards, the Spearman-Rho coefficients between the two new variables were calculated. The strengths of correlation were interpreted using Prion and Haerling's (2014) guidelines for interpretation: A range of 0.00 to 0.20 shows a negligible, 0.21 to 0.40 a weak, 0.41 to 0.60 a moderate, 0.61 to 0.80 a strong and 0.81 to 1.00 a very strong correlation.

Several Linear Mixed Models (LMMs) with Estimated Marginal Means (EMMs) were used to answer the current study's research questions. The chosen design allowed for adequate handling of the missing data of participants due to the use of EMMs. Besides, it enabled the consideration of the dependent nature of responses within the individual participants (Yang et al., 2014; Krueger and Tian, 2004). The timepoint variable was used as the repeated measurement and the participants' ID as the subject variable for each of the models. To model the repeated measurements, the autoregressive covariance structure AR (1) was used, based on the assumption that correlation between measurements within participants decreases over time (IBM, 2019). All correlation estimates were reported in unstandardised form.

First, the association between total sedentary time and state perceived psychological stress was explored. The stress variable was set as the dependent variable, whereas the total sedentary time variable was chosen as the fixed covariate, due to its continuous nature. To answer the first two research questions regarding mentally active or passive sedentary time and its relationship with stress, the same analysis was performed two more times, once with the active and once with the passive sedentary time variable as fixed covariate.

For the third research question, the moderator variable of moderate-to-vigorous physical activity was included. Thus, a moderation analysis was conducted, meaning that an interaction term was included in the model. Stress was the dependent variable and total sedentary time, physical activity and their interaction term were covariates. Next, this analysis was performed two more times, once with the active and once with the passive sedentary time variable as the covariate.

Moreover, visualisations were made for the three variables, sedentary time, physical activity and state perceived psychological stress, showing the mean values per participant as well as over timepoints. The missing data was accounted for by the EMMs used in the LMMs. Lastly, the relationships between the three variables were visualised.

Results

Split-Half Reliability Analyses

A split-half reliability analysis was performed for the stress item (SNRS-11), the two physical activity items (from the IPAQ-SF), and all revised sedentary time items (from the PAST-U). For the stress item, a significant strong correlation between the means of the first and second half of measurements was found (r = .762, p < .001). For the item of moderate physical activity, a significant strong correlation was found (r = .714, p = 0.00). For the item of vigorous physical activity, a significant strong correlation was found as well (r = .710, p < .001). The active PAST-U sum variable was found to have a significant strong correlation (r = .677, p < .001), whereas the passive PAST-U sum variable was found to have a significant moderate correlation (r = .562, p = .003), suggesting that the active items had an overall higher reliability than the passive ones. However, it could also be that there was a difference in time spent sedentary, making this method flawed when splitting one week with weekend days instead of two weeks. The individual PAST-U items were all found to have moderate to very strong correlations, which were mostly significant. Only the passive driving item turned out to have an insignificant weak correlation. For a detailed overview of all PAST-U item's correlation coefficients, see Appendix F.

Descriptive Statistics

In total, 84 participants took part in the study. Of these, 19 participants joined the study after the registration deadline (22nd of November) and, thus, could not fill out the baseline questionnaire

and informed consent. Additionally, two participants did not consent to the study's conditions. Next, 20 participants with an insufficient response rate of <70% had to be excluded. Lastly, six participants were excluded because their reported total daily sedentary time was consistently over 24 hours. This was done to avoid distorted analysis results. In total, 37 participants remained for the data analysis.

From the final cleaned dataset, 27 women and 10 men with an age range of 18 to 26 years (M= 20.64; SD= 2.13) took part. The sample consisted of mostly German students (56.8%, n = 21) and a great majority was enrolled in Psychology (83.78%, n = 31). Further, most participants were not diagnosed or suspected to have a mental disorder (83.8%, n = 31) and did not have a condition restricting their physical activity (86.5%, n = 32). For a detailed overview of the sample characteristics, see Table 3.

Table 3

Means(M), Standard Deviations (SD), Frequencies (n), Percentages (%) and Minimum and Maximum of Participants' Demographics, Sedentary Time, Physical Activity and State Perceived Psychological Stress

Variable	*n*	*%*	*M*	*SD*	*Min*	*Max*
Gender:						
Male	10	27				
Female	27	73				
Age			20.64	2.13	18	26
Nationality:						
Dutch	7	18.9				
German	21	56.8				
Other EU	5	13.5				
Other Non-EU	4	10.8				
Study programme:						
Psychology	31					
Other[c]	6					
Mental disorder:						
Yes	6	16.2				
No	31	83.8				
Restricted PA:						
Yes	5	13.5				
No	32	86.5				
Daily ST (hours):						
Total		100	9.60	3.55	1.75	23
Active		61.25	5.88	3.23	0.00	19.50
Passive		36.15	3.47	1.94	0.50	12.50
Daily PA (minutes):						
Total			57.6	1.40	0.00	8.50
Moderate			33.69	0.91	0.00	8.00
Vigorous			23.93	0.92	0.00	6.75
State stress			2.99	2.21	0	10

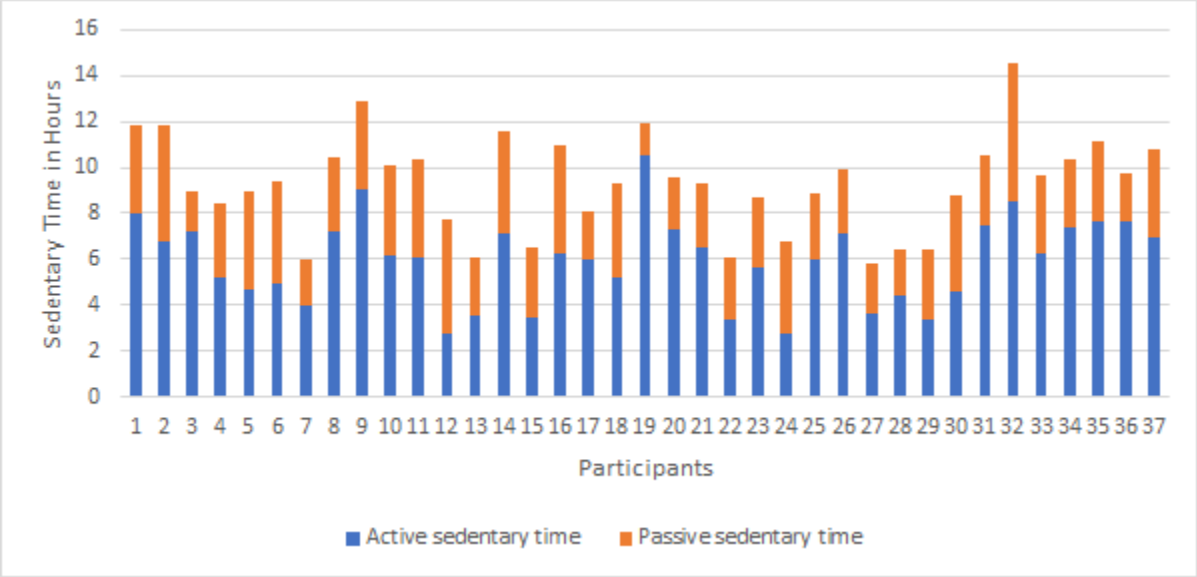
Note. Abbreviations: PA = physical activity, ST = sedentary time.
Note. [c]Other study programmes reported were Business Mathematics, Informatics, Mechanical Engineering, Mechatronics and Physiotherapy.

Overall, participants spent more time engaging in mentally active activities (61.25%) compared to mentally passive ones (36.15%). The activities participants engaged in most on average (in hours) were studying (*M = 2.32*), socialising (*M = 1.55*), and using the computer passively (*M = 1.49*). The mean of total daily sedentary in hours was 9.6 (*SD = 3.55*). Due to the high standard deviation, the frequencies were plotted to look at the median (see Appendix G). It was 9 hours of sedentary time per day, similar to the mean. The range from 1.75 to 23 hours was broad, with a distribution that was not clearly centred around the mean or the median. The mean of total daily mentally active sedentary hours was 5.88 (*SD = 3.23)*, whereas the mean for the mentally passive hours was 3.47 (*SD = 1.94*).

Looking at the mean sedentary scores per participant, it was observed that 35 participants spent more time in active activities, whereas only two spent more time in passive ones. No significant variation between participants was found for total ($F(1, 19.202) = 1.119$, $p = .406$), active ($F(1, 22.849) = 0.987$, $p = 525$) or passive sedentary time ($F(1, 30.886) = 1.014$, $p = .488$; see also Figure 3).

Figure 3

Mean Daily Active and Passive Sedentary Time in Hours per Participant



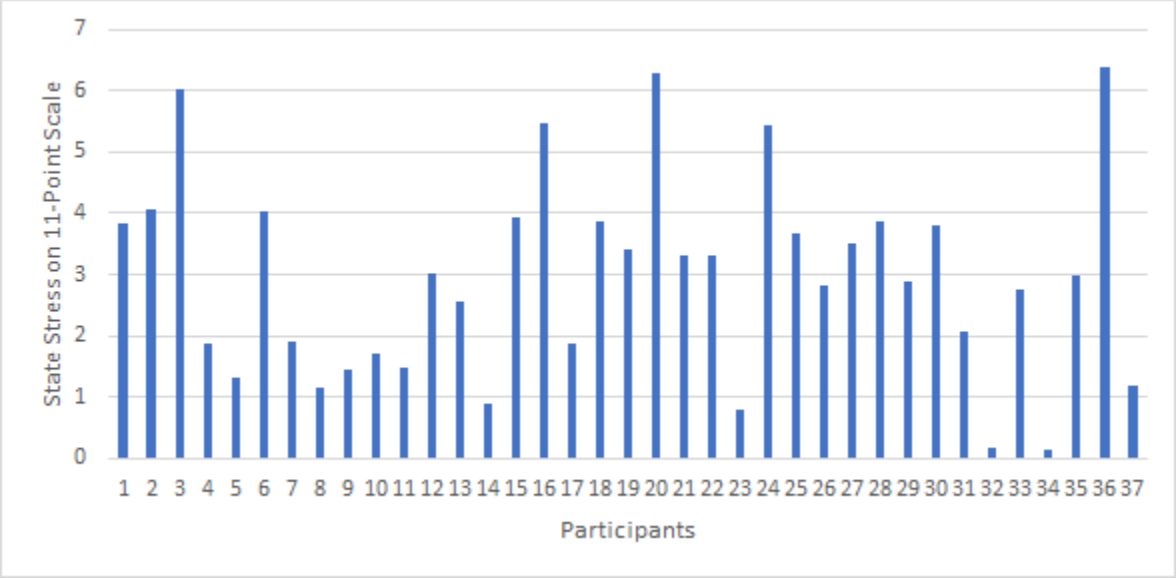
Note. Active and passive sedentary time add up to total sedentary time.

Looking at the mean sedentary scores over time, participants spent most time sedentary in total and actively sedentary on the first measurement day, a Thursday. Their total sedentary time was lowest on Sunday and Monday and their active sedentary time was lowest on Monday. The means for passive sedentary time over time fluctuated inconsistently and rather little. Participants spent most time in passive sedentary activities on Tuesday and least on Sunday. The variation between timepoints for total sedentary time ($F(1, 524.231) = 2.531$, $p < .001$) and active sedentary time ($F(1, 504.456) = 3.525$, $p < 0.001$) were observed to be significant, whereas the one for passive sedentary time was not ($F(1, 496.446) = 0.878$, $p = .616$; see also Figure 5).

The mean state stress was 2.99 (*SD = 2.21*), a relatively low score on a sample level. The mean state stress per participant ranged from 0.12 to 6.37, showing a large difference between participants (see Figure 4). Looking at the mean state stress over time, one can see an almost constant change in stress over the sessions. Generally, participants reported being most stressed in the afternoon, followed by the morning. In the evening, their stress was lowest. When looking at the weekdays, participants reported most stress on Monday, followed by Tuesday and Wednesday. They reported least stress on Sunday, followed by Saturday (see Figure 5).

Figure 4

Mean Daily State Stress on a 11-Point Scale per Participant



The mean of total daily physical activity in minutes was 57.6 (*SD = 1.4*). The total mean for vigorous physical activity was 23.93 minutes (*SD = 0.92*), whereas the total mean for moderate physical activity was 33.69 minutes (*SD = 0.91*), suggesting that participants spent on average 10 minutes more on moderate than vigorous physical activities. The mean between participants for total physical activity ranged from zero to 190.2 minutes. The variation between participants for total physical activity was not significant ($F(1, 21.454) = 1.514$, $p = .156$; see also Appendix H).

Lastly, looking at physical activity over the timepoints, the mean ranged from 33.6 to 75.6 minutes. The variation over time was shown to be significant ($F(1, 555.862) = 2.033$, $p = .005$). The physical activity of participants was highest on Thursday, after which it dropped until Saturday. It rose again on Sunday and dropped slightly on Monday. On Tuesday participants worked out significantly less again and Wednesday represented the lowest mean physical activity. Hence, participants were most active on Thursday and Sunday and least active on Saturday and Wednesday (see Appendix I).

Sedentary Time and Psychological Stress

For the first and second research questions, the relationship between sedentary time and state perceived psychological stress was assessed (see Figure 5 and Table 4). No significant relationship between total sedentary time and state perceived psychological stress was found ($B = -0.031$, $SE = 0.032$, $F(325.135,515.810) = .953$, $p = .329$). There was also no significant relationship between active sedentary time and stress ($B = 0.013$, $SE = 0.033$, $F(235.944,583.057) = .161$, $p = .689$). However, a significant relationship was found between passive sedentary time and stress ($B = -0.110$, $SE = 0.052$, $F(248.846,612.059) = 4.510$, $p = .034$). Hence, passive sedentary time and stress are negatively correlated, suggesting that the more time participants spent in passive sedentary activities, the less state stress they reported. More specifically, with every unit passive sedentary time increased, stress decreased by -0.110.

Figure 5

The Associations between Daily Total, Active and Passive Sedentary Time and Daily State Stress

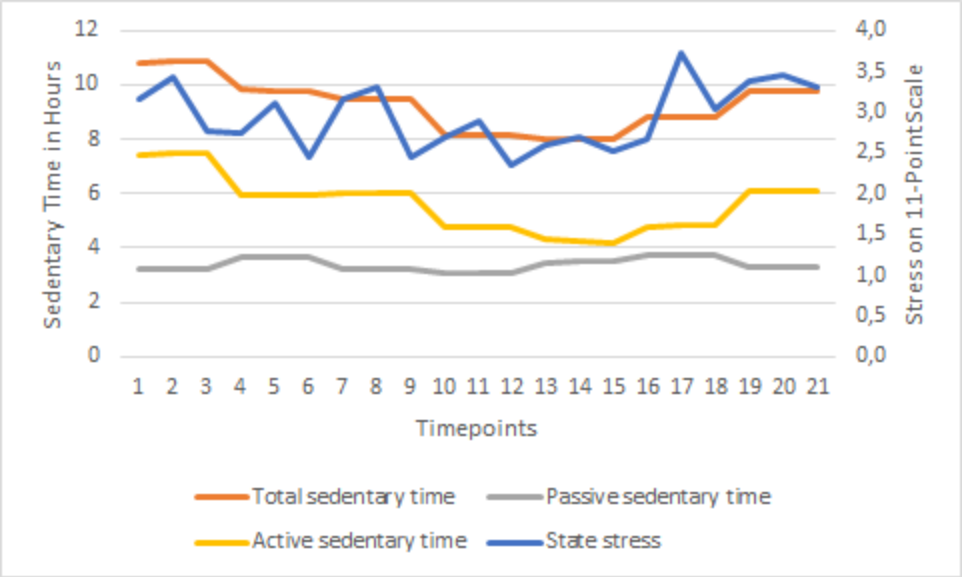


Table 4

The Association between Daily Total, Active and Passive Sedentary Time and State Stress

						95% Confidence interval	
Variable	B Estimate	Standard Error	Df	t	p	Lower Bound	Upper Bound
Total ST	-0.031	.032	515,810	-.976	.329	-.094	.032
Active ST	0.013	.033	583.057	.401	.689	-.051	.078
Passive ST	-0.110	.052	612.059	-2.124	.034	-.211	-.008

Note. Abbreviations: ST = sedentary time.

Moderation by Physical Activity

To test the last research question, moderate-to-vigorous physical activity was added into the analysis as a potential moderator of the relationship between sedentary time and state perceived psychological stress. No significant interaction effect was found for physical activity on the relationship between total sedentary time and stress ($F(1, 515.743) = .134$, $p = .714$). Further, there were no significant interaction effects of physical activity on the relation between active ($F(1, 547.824) = .158$, $p = .691$) or passive ($F(1, 652.221) = .036$, $p = .850$) sedentary time on stress

either (see also Table 5). Hence, physical activity does not seem to moderate the relationship between sedentary time and state perceived psychological stress. Further, the main effect of physical activity on state stress was tested to check if physical activity is a direct predictor of stress. The association found, however, turned out not to be significant ($F(1, 453.066) = 1.129$, $p = .289$), meaning that the amount of participant's physical activity did not affect their state perceived psychological stress significantly.

Table 5

The Moderation Analyses for Daily Total, Active and Passive Sedentary Time and Daily Moderate-to-Vigorous Physical Activity

						95% Confidence Interval	
Variable	B Estimate	Standard Error	Df	t	p	Lower Bound	Upper Bound
Moderation Analysis Total Sedentary Time and Moderate-to-Vigorous Physical Activity							
Intercept	3.44	.402	384.398	8.548	.000	2.646	4.227
total ST	-0.042	.038	544.213	-1.122	.262	-.116	.032
PA	-0.161	.199	517.200	-.811	.418	-.553	.230
total ST*PA	0.007	.019	515.743	.367	.714	-.031	.044
Moderation Analysis Active Sedentary Time and Moderate-to-Vigorous Physical Activity							
Intercept	3.016	.290	303.603	10.409	.000	2.446	3.587
active ST	0.002	.132	602.608	.048	.962	-.075	.079
PA	-0.125	.039	540.873	-.949	.343	-.383	.134
active ST*PA	0.007	.018	547.824	.397	.691	-.029	.043
Moderation Analysis Passive Sedentary Time and Moderate-to-Vigorous Physical Activity							
Intercept	3.384	.273	295.605	12.409	.000	2.847	3.920
passive ST	-0.105	.061	589.398	-1.719	.086	-.224	.015
PA	-0.068	.141	569.376	-.479	.632	-.345	.210
passive ST*PA	-0.006	.033	652.221	-.189	.850	-.071	.058

Note. Abbreviations: PA = physical activity, ST = sedentary time.

Discussion

This study aimed to investigate the association between mentally active or passive sedentary time and state perceived psychological stress over time. Concerning mentally active sedentary time, no significant association was found with state stress. A significant association was found between mentally passive sedentary time and state stress. However, this observed association was negative, suggesting the opposite direction of what was expected. Physical activity did not moderate these associations.

Evaluating the First and Second Hypothesis - Sedentary Time and State Stress

First, the potential correlation between total sedentary time and state perceived psychological stress was examined with the assumption that the two constructs would associate positively. However, in the current study no significant correlation was found. Although the current study's finding contrasts some of the previous literature, there has also been research with findings coherent with the current ones. A systematic review by Teychenne et al. (2019) suggested that there was no sufficient evidence that total sedentary time and stress were associated. This was particularly not the case for self-report studies (Teychenne et al., 2019). Hence, it could be the case that the exact relationship between sedentariness and stress needs to be researched further to clarify the actual relationship. Perhaps a change from self-report measurements to objective measures, for instance an activPAL, might be needed. Stress might also need to be reported in an objective manner. However, this might change the construct measured from perceived psychological stress to objective physiological stress, leading to potential changes in the stress levels reported.

Next, it was tested whether there was a significant correlation between sedentary time in mentally passive or active activities and perceived psychological stress. Based on recent research on sedentary behaviour and depression by Hallgren et al. (2020), it was hypothesised that the effects on state stress could be similar to the ones found on depression. Contrary to the expectations, in the current study no significant relationship was found between mentally active sedentary time and stress. This might be explained by the fact that mentally active sedentary activities have different purposes and nuances not taken into consideration. While working or studying might increase stress, as these are tasks students must do to secure their future career and financial security, other mentally active tasks such as socialising or playing computer games might decrease stress, as they are leisure time activities that are done for fun. Accordingly, mentally

active sedentary behaviours could be both a positive and negative influence on students' stress levels. Overall, these effects might cancel each other out and result in no association being found. A more nuanced approach to mental activity and mentally active tasks specifically might, thus, be needed. Moreover, it could be that the week of measurement was not a very stressful one compared to others. This could be controlled by repeating the study in a busy and taxing week, for instance during exam phase, or conducting the study over a time span of multiple weeks instead of only one.

Nevertheless, a significant negative relationship was found between mentally passive sedentary time and stress, suggesting the opposite direction as previous research suggested. The finding that passive sedentary activities seemed to lower stress in the participants of this study might be explained by looking at the reasons why individuals might engage in mentally passive sedentary tasks. One could be distraction, which is a coping behaviour that is used in response to stressors and often implies being mentally passive, for instance when using video-on-demand services or social media. It helps the individual divert their attention away from the stressor and, instead, towards more pleasant behaviours and thoughts. This increases stress levels long-term, but decreases them short-term (Tarafda et al., 2019). Specifically anxious and stressed people are prone to using distraction or escapism this way, for instance in the form of smartphone and internet use (Panova et al., 2019; Wang et al., 2015). Besides, leisure involvement, which entails engaging in leisure time activities, is often used as a form of distraction or avoidance. People may engage in this to restore their energy, so they are able to work more efficiently on a demanding task later. Using leisure time as a study break could, thus, be a way for students to escape the stressful event, experience positive feelings, and restore depleted resources (Patry et al., 2007). As many leisure activities entail being mentally passive, for instance using video on demand services, listening to music and scrolling through social media, it could be that university students actively use these activities to reduce or avoid their experienced stress. This could explain the negative relationship found. However, as this form of coping leads to higher stress levels long-term (Tarafda et al., 2019), the relationship might change with a longer study duration.

Evaluating the Third Hypothesis - Physical Activity as a Moderator

Lastly, moderate-to-vigorous physical activity was included to find out if it moderated the relationship between sedentary time and state perceived psychological stress. This was done since

several researchers argued that physical activity not only directly reduces the risk of depression and anxiety and increases quality of life (Zhai et al., 2015; Piercy et al., 2018), but also attenuates or even eliminates increased mortality risks of prolonged sitting when done moderately to vigorously (Ekelund et al., 2016). However, analyses revealed that moderate-to-vigorous physical activity did not significantly moderate any of the relationships.

Despite these findings contrasting most previous research, a study by Felez-Nobrega et al. (2020) came to a similar conclusion. Although the researchers found a moderating effect of physical activity on the relationship between sedentary time and anxiety, the same effect could not be observed for the relationship between sedentary time and perceived stress (Felez-Nobrega et al., 2020). This shows that physical activity does not have such an effect for all relationships including sedentary time, but only for certain ones, namely anxiety. It could, however, also be that the necessary variance in the variable of physical activity was missing, which might have led to a lack of correlation. Further research is, thus, needed to explore whether or not physical activity actually has a moderating influence on the relationship between sedentary time and state stress. Although previous studies suggested that light physical activity does not have the same influence as moderate-to-vigorous one (Ekelund et al., 2016), this should be tested in future research as a potential role of light physical activity on this relationship cannot be ruled out.

Sample and Means

Looking at the average sedentary time of this study's sample, the observed mean is in line with previous research. Several researchers have suggested different averages for students, ranging from seven to 12 hours of daily sedentary time (Keating et al., 2020; Castro et al., 2020; Moulin and Irwin, 2017). The current study's university students sat 9.6 hours on average, which lies within the previously suggested time frame. The university students of this sample were, thus, sitting extensive amounts of time, which is in line with previous findings. Concerning the sample's average stress level, however, the current study's results deviate significantly from previous research findings. On a 11-point scale, the current sample scored an average of 2.99, which is rather low considering the range from zero to 10. This score appears even lower compared to previous research that suggested that students deal with high levels of both short-term and continuous stress, which often manifest themselves in mental disorders (Hamaideh, 2011; Regehr et al., 2013). Even when looking at the mean scores over participants, the highest mean was a 6.37.

These results might suggest that this study's sample of university students is less stressed than expected. It could also be that the participants of this study were less stressed than the average university students due to a selection bias or that the week of measurement was a less stressful one than other weeks.

Strengths and Limitations

This study had several strengths compared to previous studies. First of all, the current study was one of the first ones investigating the associations between sedentary time, state perceived psychological stress and physical activity. It integrated the concept of mental activity, a concept not extensively researched yet, in a new context because previous research had only explored mental activity in the context of depression. It also focused on a new subgroup, namely students, which had not been investigated in the context of mental activity before. Besides, only one other study by Ekelund et al. (2016) had previously investigated physical activity as a moderator instead of an independent variable affecting health outcomes of sitting, specifically mortality risks.

Further, the ESM approach gave more detailed insights, as it enabled an exploration of the associations over time instead of only one time point. This helped capture the constant change and trends/developments of mental states and activities over time and between individuals. The subjective experience of participants was recorded in their natural environment instead of relying on observational data from a laboratory. This gave insight into participants' feelings and increased ecological validity. By sending out three questionnaires a day measuring stress, memory bias was potentially reduced as well. Lastly, strong reliabilities were found for the stress (SNRS-11) and physical activity (IPAQ-SF) items, while all sedentary behaviour (PAST-U) items, except for one measuring passive driving, were shown to have moderate to very strong reliabilities.

The current study also has several limitations. First of all, the duration of the study was nine days with only seven of them measuring all constructs, which is less than the average duration of Experience Sampling studies (Conner & Lehman, 2012; Van Berkel et al., 2017). Measuring for only one week might have caused biased measurements, as the week of the study might have been an extraordinary one compared to others, for instance exam week.

Moreover, categorising sedentary behaviour by mental activity is a relatively new concept that is based on few previous studies (Cabanas-Sánchez et al., 2018; Hallgren et al., 2018). This means that there is no comprehensive list that allows for a clear distinction between mentally active

and passive sedentary tasks. Concerning the items measuring sedentary time, it was therefore difficult to assign activities to one of the two categories. It could be the case that some items are neither strictly active nor passive, making the dichotomous categorisation too simplistic. Related to this, activities belonging to the same category could still differ greatly. For example, online shopping might be less taxing in terms of stress than studying for an exam, despite them belonging to the same category of mentally active activities. This suggests a potential need for a more nuanced approach to mental activity. It is suggested to measure mental activity on a continuum by using a physiological measure of mental workload, for instance blood pressure or skin conductance. These could assess more detailed facets of mental activity and are unobtrusive measures that can be used without disturbance of participant's routines (Charles & Nixon, 2019).

Lastly, several participants did not fully understand the items or instructions for reporting sedentary time. There were six participants with reported daily sitting times over 24 hours and many other participants with highly unrealistic sedentary times that imply they only slept around two hours every night. Hence, it could be that some participants reported certain timeframes twice instead of only reporting their main activity, for instance reporting three hours of studying while also reporting three hours of active computer use even though these were done simultaneously. It is, thus, not clear to what extent the current study's results are flawed due to wrong reporting.

Future Research

Considering the current study's findings and limitations, several recommendations for future research can be proposed. Since this study had findings going against the expectations set by previous research on sedentary behaviour, it is of interest to analyse the relation between sedentary time and stress in university students further to see if similar findings are achieved. As physical activity did not significantly moderate the researched relationship, it is advised to investigate other variables that might explain the associations better. For instance, future studies could test whether light physical activity might play a role, as this cannot be ruled out.

Moreover, longer duration should be considered for future studies to allow for a comparison of different weeks. This would allow for more representative and insightful findings. Further, the construct of mental activity should be researched in depth before using it in studies exploring associations. A more nuanced approach to mental activity, describing the construct on a continuum rather than as a simple dichotomy, might help achieve more valid results.

Concerning the type of measurement for sedentary time, it should be considered to switch to an objective type of measurement, for instance physiological tracking devices such as an activPAL. This has several advantages including a reduction in participant burden and memory bias, as participants would not need to remember and report their sedentariness themselves, but could rely on objective and accurate measurements. Mistakes in memory or misunderstandings of how to report which activity would, thus, be ruled out. In order to investigate mental activity modes as well, a physiological measure of mental workload, for instance blood pressure or skin conductance should be included. This would also allow for a more nuanced understanding of mental activity, changing it from a dichotomy to a continuum. Looking at the relatively low mean results for stress that go against previous literature's suggestions, a different measurement type should be considered as well. Measuring stress objectively with physiological tracking might result in different results. However, this might change the construct measured, as perceived psychological stress and objective physiological stress are not the same. An individual might, for instance, experience physiological stress, but not interpret their experience as such. Thus, reported perceived stress might not be in line with objective measures, which suggests an approach including both types of measurement to check for differences between the results.

Conclusion

Overall, the current study casts doubt on previous research on the topic of sedentary behaviour, as its findings go against existing studies' suggestions that mentally active sedentary time is negatively and mentally passive sedentary time is positively correlated with state perceived psychological stress. Physical activity was suggested to moderate these relationships by attenuating or eliminating negative health outcomes of being sedentary. However, the current study has found no significant relationship between mentally active sitting and state stress. Mentally passive sitting was negatively associated with state stress, suggesting that sitting passively reduced stress in participants. Physical activity did not moderate any of these relationships, casting doubt on its positive influence. Overall, the high levels of sedentary time and their associated negative health outcome show clearly that university students' mental and physical wellbeing are threatened. Thus, more research on the topic of sedentary behaviour is needed to gather insights into how this risk groups' stress and sedentary levels can be reduced.

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Appendices

Appendix A: The Relevant Items of the Baseline Questionnaire

How old are you?

What gender do you identify with?
- Female
- Male
- Other

What is your nationality?
- Dutch
- German
- Other EU nationality
- Other Non-EU nationality

Which study programme are you enrolled in?

Are you diagnosed or suspected to have a mental disorder?
- Yes
- No

Do you have any condition which might affect your time spent in physical activities?
- Yes
- No

Appendix B: The Relevant Items of the Morning Questionnaires

How long were you sitting while studying yesterday? (**include** the time at university, during lectures, tutorials, meetings, group discussions, self-study, study from home, etc.)

Minutes

How long were you sitting at your workplace or working from home in a paid position yesterday? (Examples: babysitting, sitting at the reception, minding a stall/shop, data entry/administrative paper work, tutoring, etc.)

Minutes

Thinking again of yesterday, please estimate the **total** time that you spent sitting to travel from one place to another **driving yourself**. **Do not include** any time you were standing up while travelling.

Minutes

Thinking again of yesterday, please estimate the **total** time that you spent sitting to travel from one place to another **using public transportation/not driving yourself**. Please **include** sitting and waiting for transport. **Do not include** any time you were standing up while travelling or

Minutes

Please estimate the **total time** you spent sitting or lying down to watch TV or DVDs? This **does not include** Video-on-Demand watching.

_____

Minutes

Please estimate the **total time** you spent sitting or lying down to play games on the TV yesterday, such as PlayStation/Xbox?

_____

Minutes

Please estimate the **total time** yesterday that you spent sitting or lying down and **using the computer actively.** (For example, **include** time spent playing games, reading, online shopping on your smartphone/tablet/computer).

_____

Minutes

Please estimate the **total time** yesterday that you spent sitting or lying down and **using the computer passively**. (For example, **including** time spent watching Video On Demand (e.g. YouTube, Netflix), scrolling through social media.

_____

Minutes

Please estimate the **total time** yesterday that you spent sitting or lying down while reading during your leisure time. **Include** reading in bed but **do not include** time spent reading for paid work or for study.

_____

Minutes

Please estimate the **total time** yesterday that you spent sitting down for eating and drinking, **including** meals and snack breaks.

_____

Minutes

Please estimate the **total time** yesterday that you spent sitting down to socialize with friends or family, regardless of location (at university, at home or in a public place). **Include** time spent on the phone (e.g. calling, chatting, texting etc.)

_____

Minutes

Please estimate the **total time** you spent sitting or lying down engaging in creative hobbies (e.g., drawing, playing the guitar etc.).

_____

Minutes

We are interested in any other sitting or lying down that you may have done that you have not already told us. For example, this **could include**; playing board games, listening to music or for religious purposes.

Please estimate the **total time** that you spent sitting or lying down engaging in these actions. (**DO NOT include** time that you have told us about in the previous answers).

_____

Minutes

How much time in total did you spend doing moderate physical activity yesterday (e.g. carrying light loads, bicycling at a regular pace, or doubles tennis)?

_____

Minutes

How much time in total did you spend doing vigorous physical activity yesterday (e.g. heavy lifting, digging, aerobics, or fast bicycling)?

_____

Minutes

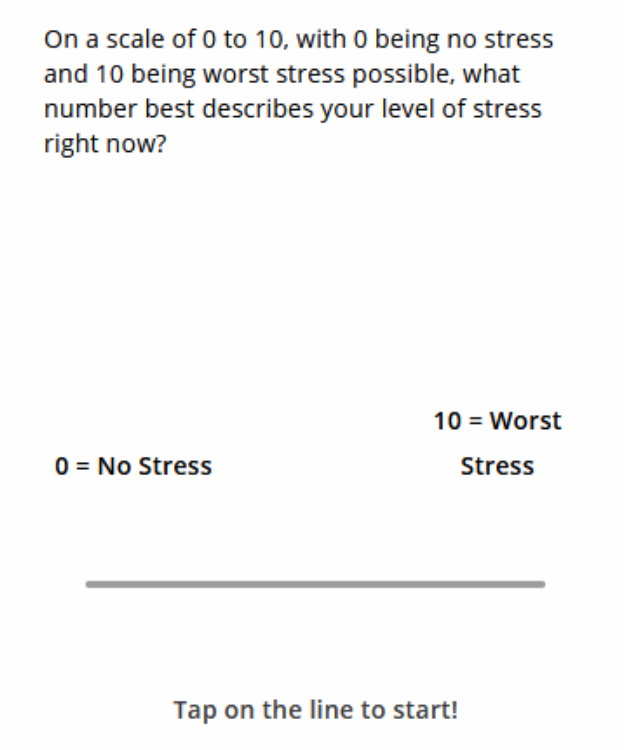
On a scale of 0 to 10, with 0 being no stress and 10 being worst stress possible, what number best describes your level of stress right now?

0 = No Stress **10 = Worst Stress**

_____

Tap on the line to start!

Appendix C: The Relevant Items of the Afternoon and Evening Questionnaire



Appendix D: The Informed Consent

Thank you for participating in our study on sitting behaviour! Please read the following information thoroughly.

The goal of this research is to explore the relationship between sitting behaviour and mental health-related constructs. With your participation in this research, you will help us contribute to the scientific knowledge of sitting behaviour and its relationship to mental health.

You are eligible to participate in this study if you are at least 18 years old, proficient in English, and enrolled at a university or university of applied sciences.

The study will be conducted over a period of nine days. At the start of the study, you will be asked to fill out a baseline questionnaire with questions about demographics and personality traits. This questionnaire will take about ten minutes to fill out. After that, you will receive three short questionnaires daily via the Ethica App. Please make sure that the notifications on your device for Ethica are turned on.

Participation in this study is not expected to pose any risks. One possible consequence is an increased awareness of your daily mood, behaviour, academic pressure, and feelings. For this reason, please consider your participation in this study carefully if you are sensitive to these topics. This might be especially relevant for you if you are diagnosed with or suspected to have a mood and/or anxiety disorder.
Your participation in this study is entirely voluntary. If you wish to withdraw from this research, you can do so at any time without giving a reason. All your answers will be treated confidentially. That is, all personal data will be anonymized and will not be published and/or given to a third party. Hence, the data will be used for this study only. The study has been approved by the Ethics Committee of the University of Twente. If you have any questions or concerns before, during or after your participation, do not hesitate to contact the researchers:

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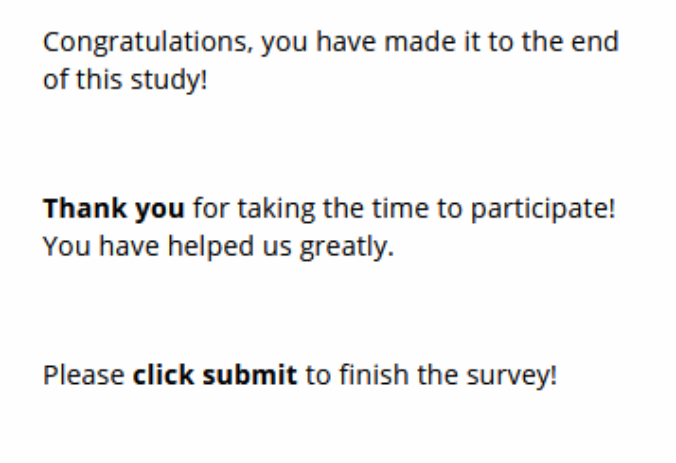
I hereby declare that I have fully read and understand the text above and I am willing to participate in this study. By ticking 'Yes', I actively consent to participate in this study and the processing of my data.

Appendix E: The Last Information Page with a Thank You

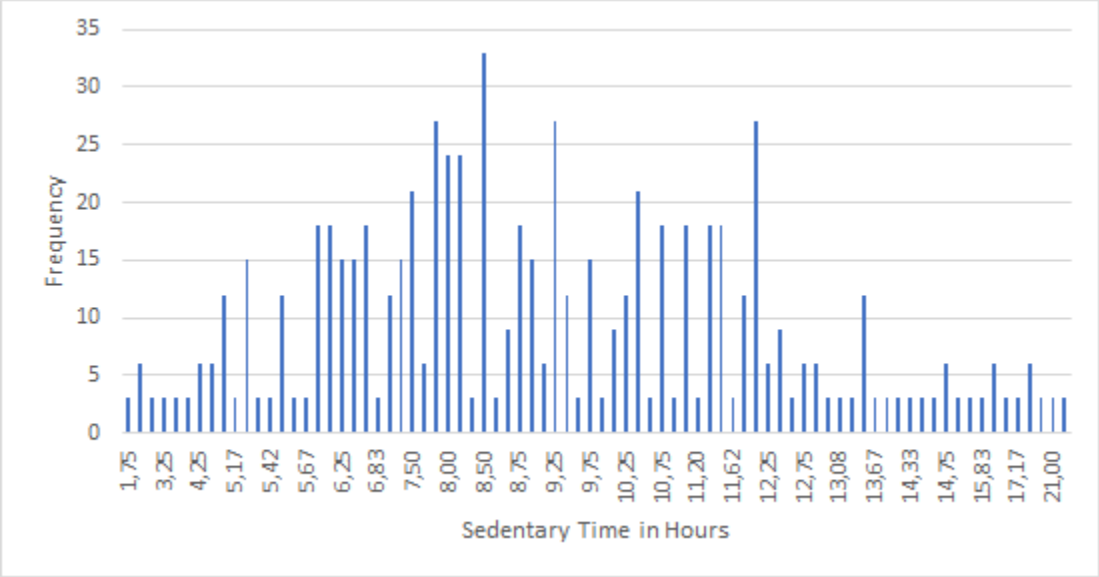


Appendix F: Spearman's Rho Correlation Coefficient (r), Interpretation and Significance (p) for all Revised PAST-U Items

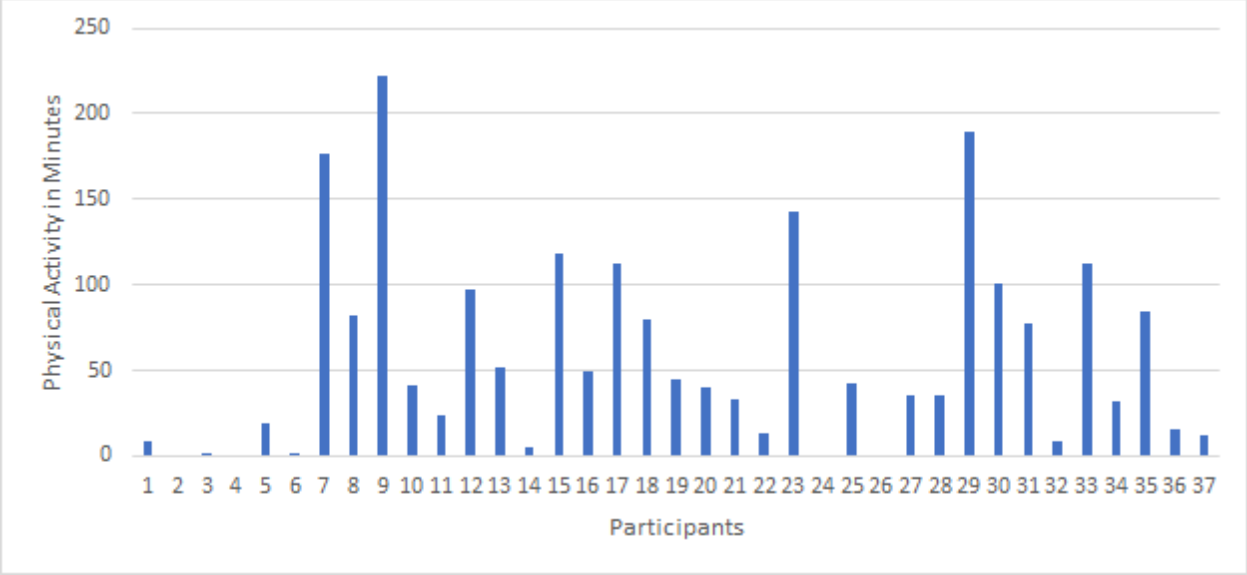
PAST-U item	Spearman's Rho Coefficient (*r*)	Significance (*p*)
Active total	.677	.000
Passive total	.562	.003
Studying	.622	.001
Working	.603	.001
Active Driving	.687	.000
Passive Driving	.240	.237
TV or DVD	.510	.008
Video Games	.706	.000
Active PC	.478	.014
Passive PC	.690	.000
Reading	.746	.000
Eating and Drinking	.426	.030
Socialising	.787	.000
Creative Hobbies	.901	.000
Other	.729	.000

Note. The correlations were interpreted using Prion and Haerling's (2014) guidelines for interpretation (see also Data Analysis part).

Appendix G: Frequencies of Daily Total Daily Sedentary Time in Hours



Appendix H: Mean Daily Total Physical Activity in Minutes per Participant



Appendix I: Mean Daily Total Physical Activity in Minutes over Timepoints