# The Influence of Context and Mental Activeness on the Relationship between Sedentary Behaviour and Mood: An Experience Sampling Study

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Abstract

University students are a highly sedentary subgroup of the population. High levels of sedentary behaviour (SB) are associated with various detrimental health effects. In the past years, SB has also increasingly been related to mental health risks like depression. However, most research of the past years has found inconsistent results concerning this relationship, and little is known about possible contributing factors. Therefore, this study has built upon a newly proposed framework to investigate the effect of context and mental activeness of SB on students' mood. The daily sitting time of 34 ($M_{age}$ = 22.38, $SD_{age}$ = 2.2; 76.5% female) university students was measured over the period of one week. Additionally, participants answered two momentary assessments per day about the sedentary context, mental activeness, and their state mood. Importantly, this study examined these aspects during the COVID-19 restrictions that obligated students to study from home. The results showed that university students sat 9.4 hours per day on average during a week of the pandemic. Students' SB was mostly mentally active (70%) and during leisure (59%), and they perceived more positive than negative mood. Furthermore, visual analyses indicated that all these aspects, as well as their stability over time, could vary strongly between students. However, no significant relationships between daily sitting time, context or type of SB, and state mood were identified. The results from this study have shown the individual differences in sedentary characteristics and, thereby, demonstrated the complexity of SB. That is, additional analyses of selected cases indicated fluctuations in sitting time, contexts, and mental activeness over time as well as differences in these aspects between students. These findings further contribute to a more nuanced understanding of SB and its influence on students' mood.

Keywords: *Sedentary behaviour, context, mental activeness, mood, depression experience sampling, COVID-19.*

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## 1. Introduction

Over the last decades, the technological, social, and physical factors of people's daily life have changed increasingly. Among many other things, these changes have also affected the sedentary behaviour of individuals (Owen, Healy, Matthews, & Dunstan, 2010). While the needs for physical activity have decreased, levels of sedentary behaviour have risen (Du et al., 2019; Hadgraft et al., 2016). In a meta-analysis, the median sitting time across different populations was found to be 8.2 hours per day measured by accelerometers (Bauman, Petersen, Blond, Rangul, & Hardy, 2018). Given this development, research on sedentary behaviour has increased more than tenfold in the past 20 years (Biddle et al., 2019). Within this growing field, the current study aims to contribute to a better understanding of the association between students' sedentary behaviour and depression, whereby the influence of contexts and types of sedentary behaviour is emphasized.

In most of the research, sedentary behaviour (SB) has been defined as any waking behaviour in a sitting, reclining, or lying position that does not exceed an energy expenditure of ≤1.5 metabolic equivalents (METs) (Tremblay et al., 2017). Common SBs include tv watching, working while seated, video gaming, or sitting during transportation (de Rezende, Rey-López, Matsudo, & do Carmo Luiz, 2014; Tremblay et al., 2017). Importantly, SB is a distinct behavioural act that is independent from physical inactivity, which refers to insufficient levels of exercising to promote health gains (Biddle et al., 2019; Lubans et al., 2011; Tremblay et al., 2017). Therefore, individuals can be sitting a lot, for example during work, but still engage in physical activity in their leisure. On the contrary, individuals can also be sitting little in their job, but perform no physical activity in their free time (Biddle et al., 2019).

Similar to this behavioural distinction, detrimental health effects have been identified for SB independent of physical inactivity, although they are reduced for people who still engage in high levels of exercising (Biddle et al., 2016; Biswas et al., 2015). Overall, high levels of SB (7–8h) are associated with type 2 diabetes (Wilmot et al., 2012), cardiovascular disease (Bellettiere et al. 2019; Young et al., 2016), obesity, (Chastin, Egerton, Leask, & Stamatakis, 2015), and all-cause mortality (Ku, Steptoe, Liao, Hsueh, & Chen, 2018; Loprinzi, Loenneke, Ahmed, & Blaha, 2016). A possible means to reduce daily sitting time and preserve oneself from these health risks are more frequent breaks to interrupt SB (Healy et al., 2008; Biddle et al., 2019).

But SB is not only related to individuals' physical health. Although less investigated, research of the recent years has increasingly focused on associations between SB and mental health (Faulkner & Biddle, 2013). High levels of SB are mostly associated with depression (de

Wit, van Straten, Lamers, Cuijpers, & Penninx, 2011; Teychenne, Ball, & Salmon, 2010; Vancampfort, et al., 2017) but also with other mental health risks such as anxiety (Rebar, Vandelanotte, van Uffelen, Short, & Duncan, 2014; Teychenne, Conistigan, & Parker, 2015) or psychological distress (Hamer, Coombs, & Stamatakis, 2014). In a meta-analysis, consisting of 13 cross-sectional and 11 longitudinal studies, Zhai, Zhang, and Zhang (2015) have identified a statistically significant association between sedentary time and the risk of depression in the pooled data. Similar to the benefits of sedentary interruptions for physical health, Hallgren and colleagues (2020d), found that those who broke up sitting more frequently in their leisure were at a lower risk to develop depressive symptoms. Based on this, reducing the time spent sitting is also important to improve one's mental well-being.

Considering these detrimental health effects, university students constitute a particularly relevant risk group of the young adult population. For students, prolonged sitting is often enhanced since activities like studying, attending lectures, or writing assignments require long periods of sitting (Carballo-Fazanes et al., 2020; Cotten & Prapavessis, 2016). In a meta-analysis, students' average daily sitting time was found to be 7.3 hours when assessed through self-reports, and even 9.8 hours when measured objectively by accelerometers (Castro, Bennie, Vergeer, Bosselut, & Biddle, 2020). These levels of SB are critical, considering that the health risks described above increase significantly at a threshold of 7 to 8 hours (Chau et al., 2013; Patterson et al., 2018). Alarmingly, a meta-regression analysis has shown that students' sitting time has been further increasing over the last 10 years (Castro et al., 2020). In addition, university students have been sitting even more since the start of the Covid-19 pandemic (Ammar et al., 2020; Romero-Blanco et al., 2020), and a recent study has found a mean sitting time of 11 hours during the lockdown (Bertrand et al., 2021).

Next to the increased engagement in SB, university students are also at a high risk to become depressed. According to a review on university students' depression prevalence, students experience higher rates of depression than the general population (Ibrahim, Kelly, Adams, & Glazebrook, 2013). Strikingly, the weighted mean prevalence of 24 included studies was found to be 30.6%. As with levels of SB, the already high depression levels among university students have gone further up since the start of Covid-19 (Debowska, Horeczy, Boduszek, & Dolinski 2020).

While increasingly investigated on their own, it is still unclear how SB and the experience of depressive symptoms are related to each other. Based on the DSM-5, depression is characterized by changes in mood as well as cognitive and physical symptoms (American Psychiatric Association, 2013). In fact, one of the effects of SB on depressive symptoms

appears to be mood (Zhai et al., 2015). When sedentary time was manipulated experimentally, longer sitting times have led to increased negative mood (Endrighi, Steptoe, & Hamer, 2016) and increased depressive symptoms (Edwards & Loprinzi, 2016).

Simultaneously, the oppositive seems to be true as well. Over the course of a 1-year study, DeMello et al. (2018) have found a bidirectional association between SB and mood. While higher SB was related to worsened mood, mood did also predict levels of SB. Although this reciprocity might seem intuitive, these findings are in some conflict with the general hypothesis of earlier research that expects a one-directional relationship. While this finding does not necessarily disprove this idea, it signals how complex the relationship between SB and depression might be.

Adding to this complexity, the context in which SB takes place may be just as important as the direct associations between SB and depressive symptoms. In prior research, SB is acknowledged as a complex behaviour that is influenced by many different factors (Hadgraft, Dunstan & Owen, 2018). An ecological model of SB that incorporates such factors has first been put forward by Owen et al. (2011). In their model, SB is categorized by the different domains in which people are sedentary. These domains include leisure, occupation, transportation, and the domestic environment. Within each domain, the contexts are different and, therefore, the factors that contribute to people's engagement in SB. In the case of university students, sedentary study activities can occur in different occupational contexts (Carballo-Fazanes et al., 2020; Cotten & Prapavessis, 2016). Depending on such a specific context, different factors are influencing students' SB.

Regarding mental health, these different domains of SB play an important role, too. Just recently, an additional framework that builds upon this ecological model has been created by Hallgren, Dunstan, and Owen (2020a) to specifically investigate the influence of other factors on the link between SB and depression (see Figure 1).

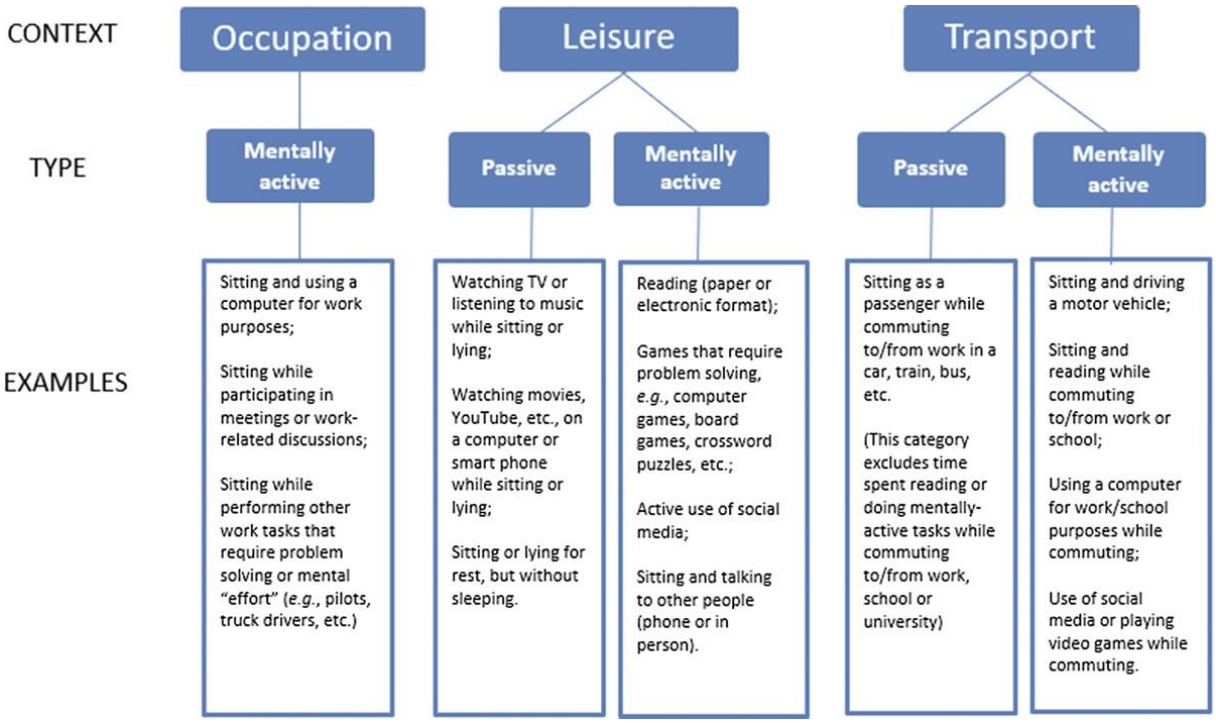


*Figure 1.* Framework for assessing sedentary behaviour across contexts and types (Hallgren et al., 2020a).

In addition to the contextual factors *occupation*, *leisure*, and *transport*, this framework further distinguishes between types of mentally *active* and *passive* SB. This way, SB in one of these contexts can be further differentiated as one of the two types. Because most tasks at work require concentration, occupational SB is considered to be mentally active in general. During leisure, passive SBs include watching TV, movies or YouTube, smartphone use, and sitting or lying while resting without sleeping. Active SBs in this context are reading, gaming, active social media use, and sitting during social interactions. During transport, commuting as a passenger is regarded as passive SB if no additional tasks are performed simultaneously. SB that is considered active during leisure such as reading, computer use, or social interaction is also seen as active SB in the context of transport. Also, driving a vehicle is regarded as active SB.

This framework has been proposed due to recent evidence suggesting that rather than the SB itself, the type of SB, being either mentally active or passive, is more predictive in terms of the risk to become depressed. SB that is mentally passive and occurs during leisure has been associated with an increase in depressive symptoms and less psychological well-being (Hallgren et al., 2018; Hallgren et al., 2020b). In contrast, more active SB, mostly in the occupational domain, might even protect from the risk of depression (Hallgren et al., 2018;

Hallgren et al., 2020c; Kikuchi et al., 2014). In support with this, a 2–year study has identified positive associations between high levels of TV viewing (≥6h) and depressive symptoms, while internet use and reading were negatively associated with depressive symptoms (Hamer & Stamatakis, 2014). Based on this, it is possible that the bidirectional association between SB and mood that was found by DeMello et al. (2018), might be explained by more nuanced factors such as contexts and types of SB. Unfortunately, little attention has been paid to the context of SB and, apart from TV viewing, no types of SB have been investigated until now (Hallgren, et al., 2020a).

Instead, previous research has been circumscribed by methodological limitations. Until now, most studies in this field employed cross-sectional designs that can only identify the presence or absence of a relationship between SB and depression. In fact, Zhai et al. (2015) have noted in their meta-analysis that, although they have found a significant association in the pooled data, a large proportion of the included studies did not find any relationship. Therefore, the authors have stressed the need for other methodological approaches that allow to investigate the influence of additional factors on this relationship (Zhai et al., 2015; Hallgren et al., 2020a).

To overcome these limitations and follow the demand for new approaches, this study employs an experience sampling method (ESM). ESM is a research method in which real-time data about momentary states, like mood, is collected repeatedly within people's natural environment (Connor & Lehman, 2012). More specifically, similar measurements are taken multiple times per day over a specific time span resulting in intensive longitudinal data (Walls & Schafer, 2006). From these measurements, analyses can identify changes within individuals over time as well as compare these changes between participants (Conner & Mehl, 2015).

Due to these characteristics, ESM has been especially effective when assessing individuals' mood. Since mood is measured in the moment of time, recall biases of more retrospective methods are avoided (Fahrenberg, Myrtek, Pawlik, & Perrez, 2007; Stone, Shiffman, Schwartz, Broderick, & Hufford, 2002). This is particularly relevant for mood assessments as retrospective reports have been shown to be distorted by the time passed and the current affect in the of moment the postponed measurement (Beck, 1963; Kihlstrom, Eich, Sandbrand, & Tobias, 2000). Secondly, ESM allows to take the interactive nature of psychological phenomena into account. This way, people's fluctuations in mood throughout the day can be identified and compared (Connor & Lehman, 2012). Lastly, ESM measurements are taken within participants' real-world environment, resulting in more natural behaviour and more accurate data (van Berkel, Ferreira, & Kostakos, 2017; Verhagen, Hasmi, Drukker, Van

Os, & Delespaul, 2016). As a result, the ecological validity of these measurements is higher than in commonly used questionnaires (Stone, Shiffman, Atienza, & Nebeling, 2007).

Most important for this study, these advantages of ESM allow to get a better understanding of how people's changes in psychological phenomena, like mood, might relate to certain real-world contexts and behaviours, like SB (Scollon, Kim-Prieto, & Scollon, 2003). While less implemented in SB research, ESM has become the most recommended and promising method to study within-subject associations of mood and physical activity (Kanning, Ebner-Priemer, & Schlicht, 2015). In this closely linked line of research, ESM also enables to investigate the dynamic interaction between mood and a particular behaviour, in this case physical activity (Bussmann, Ebner-Priemer, & Fahrenberg, 2009; Ebner-Priemer & Trull, 2009). Therefore, this study uses ESM to investigate how different contexts and types of students' SB can be described over time and how these changes are related to fluctuations in mood.

As in the moment of this study, university students in the Netherlands are still restricted by current COVID-19 measures (Ministerie van Algemene Zaken, 2021). The university study has been moved to an online environment, traveling is restricted, and contact must be minimized. This means that students must study from their homes, while mobility and interaction are strongly limited. Given this situation and the development of university students' SB and depression risk (Castro et al, 2020; Debowska et al., 2020), it is important to gain more insight into these issues and their relationship in order to inform health policies and enforce students' well-being accordingly. Therefore, this study firstly concerns the explorative research question:

1. *What are the characteristics of university students' SB during Covid 19?* For this, the following sub-questions are explored: (1.1) *How much daily sedentary time is reported by Dutch university students during Covid-19?* (1.2) *To what extent are Dutch university students sedentary in the contexts of occupation, leisure, and transportation during Covid-19?* (1.3) *To what extent do Dutch university students engage in mentally active and mentally passive SB during Covid-19?* (1.4) *How do SB and state mood vary over time among Dutch university students during Covid-19?*

Secondly, this study aims to investigate the following main research question:

2. *How are different contexts and types of sedentary behaviour associated with depressive symptoms among university students during Covid-19?* Based on the previous research, it is hypothesized that (H1) *higher total sedentary time is associated with more negative state mood,* (H2*) for occupational sedentary behaviour, the association between sedentary time and negative state mood decreases,* and (H3*) for mentally active sedentary behaviour, the association between sedentary time and negative mood decreases.*

## 2. Method

### 2.1 Design

This study employed an experience sampling design (ESM) to measure sedentary time and state mood as well as the additional factors context and type of sedentary behaviour. Participants answered multiple surveys per day about these topics via the smartphone application Ethica. Recently, smartphones are increasingly implemented in ESM studies that measure state mood, and it has been concluded to be effective for this approach (van Berkel, et al., 2017; Yang, Ryu & Choi, 2019). Through their smartphones, participants have received notifications at random moments within specified time frames (10:00-13:00 and 17:00-20:00) to signal that the next questionnaire needed to be completed. This method is called signal-contingent sampling and allows to create a representative time schedule while avoiding data distortion due to participants' expectancy effects (Alliger & Williams, 1993; van Roekel, Keijsers & Chung, 2019).

After an initial collection of demographical information, participants started on the following day to answer repetitive questionnaires twice a day over the course of eight days. Each questionnaire measured the current state mood as well as the context and type of SB. In addition, the first measurement of each day also assessed the total sitting time of the previous day. Therefore, one additional measurement was taken on day eight in order to measure the total sitting of that last day of the consecutive week. Because these assessments were rather long compared to other ESM studies, it was decided to measure the constructs twice a day to reduce the burden on participants (Yang et al, 2019). In conclusion, participants took part in this study for nine following days and needed to complete 16 assessments in total. As a result of this design, it was able to collect extensive longitudinal data about students' state mood, sedentary time, as well as the context and type of SB over the course of one week. The data was collected between 09.04.2021 and 09.05.2021. This study was approved by the Ethics Committee of the University of Twente (request number 210263).

## 2.2 Participants

The participants were exclusively students at universities or other higher education and, therefore, belonged to the target group of this study. Participants with other occupations than studying were excluded from this research. Next to this, other inclusion criteria were an age of 18 years or older, a proficient understanding of the English language, and the availability of a smartphone with an Android or iOS system to use Ethica.

Students were primarily recruited via convenience sampling by the three researchers who were involved in this joint data collection. In a few cases, snowball-sampling was employed; some participants have contacted befriended students to take part in this study. Additionally, participants were recruited over the SONA system of the University of Twente. Students who participated through this system received SONA points that are necessary for their graduation. Other participants did not receive any gratification.

For this study, a sample size of 30 participants was approached since this size is considered to provide sufficient reliability for ESM studies (Conner & Lehman, 2012). Moreover, the median sample size of ESM studies was found to be 19 (van Berkel et al., 2017). Based on this, the proposed sample size and characteristics constituted an appropriate objective to investigate the research topic of this study.

## 2.3 Materials and Measurements

### *2.3.1 Ethica*

Ethica is a research application that allows to present specific measurements repeatedly on participants' mobile phones. For this reason, Ethica is starting to become used in more recent ESM studies (e.g., Pouwels, Valkenburg, Beyens, van Driel, & Keijsers, 2021). Once downloaded, participants receive notifications from the app and can fill in subsequent questionnaires at specified time points. Next to different surveys, additional information like the informed consent (see Appendix A) or contact details of the researchers can be integrated into Ethica. This way, this entire data collection of this study could be done via this application, enabling participants to answer all questionnaires during their normal life and in their own environments. Moreover, the use of Ethica allowed to avoid physical contract during COVID-19. The full license for Ethica was provided by the University of Twente.

During the study, participants answered the measurements described below through Ethica on the smartphone. Moreover, participants answered additional questions about rumination and MVPA that were part of two other research projects (for the entire questionnaire, see Appendix B).

### *2.3.2 Sociodemographic Information*

Participants were asked to report their age, occupation (*university student, higher education, other*), gender, and nationality (*German, Dutch, other*).

### *2.3.3 Sedentary Time*

Sedentary time was assessed through a self-report questionnaire. For this objective, the "Past-day Adults' Sedentary Time-University" (PAST-U) was chosen. This questionnaire has been developed from the original PAST (Clark et al., 2013) to specifically measure university students' sedentary time (Clark, Pavey, Lim, Gomersall & Brown, 2016). In this measurement, students are asked to recall their sitting time of the prior day within specific contexts: *study, work, transportation, eating or drinking, television viewing, computer use, reading, socializing,* and *other purposes*. The sedentary time reported within each context can then be assessed individually or used to calculate the students' total sedentary time from all items. The multi-item construction of this questionnaire is an advantage as it has been concluded in a recent review on SB self-report measurements by Prince et al. (2020) that these measurements allow a more accurate measure than single-item surveys. In the past, the Past-U has shown acceptable criterion validity compared to objective accelerometer measurements (ICC = 0.64; mean difference = 0.08h, SD = 2.04h) (Clark et al., 2016).

In this study, the PAST-U has been slightly adapted due to the time constraints of the ESM approach and the Covid-19 restrictions. Therefore, the item about sitting time during transport has been removed as students were not expected to travel a lot during Corona. Additionally, the items concerning studying and working were combined since participants of this study were exclusively students, unlike in the original study by Clark and colleagues (2016). Lastly, the items about sitting time during leisure spend tv watching and using the computer were combined to decrease further time burdens for participants. This way, the final product was a shortened version of the PAST-U consisting of 6 questions that remained close to the original but also fitted the specific context and methodological approach of this study.

### *2.3.4 Mood*

Mood was also assessed through a self-report questionnaire. Thereby, mood was measured based on the two-factor model in which facets of mood are represented by the dimensions of negative affect (NA) and positive affect (PA) (Watson & Tellegen, 1985). NA incorporates negative feelings whereas PA comprises the experience of negative feelings. To measure this conception of mood, the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) was used (Thompson, 2007). This questionnaire is a reduced form of the original PANAS that was developed by Watson, Clark, and Tellegen (1988). Similar to the original, this short form measures the subscales PA and NA, but the number of items has been

reduced from 10 to five items per scale. Like in full length PANAS, this shorter questionnaire asks participants: "*Thinking about yourself and how you feel, to which extent do you generally feel…?*". Participants can then indicate on a 5-point Likert scale the degree to which they feel, for example, *inspired, attentive* (PA) or *afraid* (NA). The sum score of the five items per scale then represents one of the dimensions of the two-factor of mood (Watson & Tellegen, 1985).

In the past, the I-PANAS-SF has demonstrated good psychometric properties (Thompson, 2007). This short version was found to have high correlations with the full length PANAS (.92), high test-retest reliability over 8 weeks (.84), internal consistency ($\alpha = .78$), and showed good convergent validity compared to other measures of subjective well-being (Thompson, 2007). All in all, the I-PANAS-SF forms a reliable and valid instrument to measure mood across different populations, making it an appropriate measurement for the diverse target group of university students.

To measure state mood multiple times a day in this study, the I-PANAS-SF was further reduced. This reduction is common practice as Degroote, DeSmet, De Bourdeaudhuij, Van Dyck, and Crombez (2020) have concluded in their review on mood measurements in ESM studies. They found that most ESM studies that measured mood formed short survey versions by using items from existing validated questionnaires, especially the PANAS. This way, the burden on participants could be decreased study while retaining as much of the psychometric properties as possible. Therefore, the items with the highest factor loadings were chosen for the PA and NA subscales (Thompson, 2007). As a result, the items *attentive* (.77)*, determined* (.77), and *active* (.74) were selected to assess PA, and the items *nervous* (.76), *afraid* (.75), and *upset* (.68) were chosen to measure NA, whereby the question was transformed into: "*Right now, to what extent do you feel…?*". In a large study that compared trait mood and state mood, using the original PANAS for every measurement, these items were also found to have high factor loadings for both types of mood assessment (Merz & Roesch, 2011). In the end, this constructed questionnaire consisted of three items per scale, allowing to measure mood twice a day while remaining close to the original PANAS and I-PANAS-SF.

#### *2.3.5 Context and Type*

Lastly, the context and type of SB were measured based on the proposed framework of Hallgren et al. (2020a) (see Figure 1). First, participants were asked: "*Right now, what context are you in?*". The three possible answer options included the contexts that are described in the framework: *Occupation/study*, *leisure*, and *transport*. Following, the subsequent question "*What were you doing right before you were answering this questionnaire?*" was presented to assess the type of SB. Thereby, answer options were based on the response to the first contextual

item. For each context, different possible activities could be indicated by the participants. These activities were also based on the examples given in the framework (see Figure 1), for example, "*Sitting and using the computer for work and study purposes*" in the context of occupation/study. Additionally, the answer option "*not sitting*" was available, no matter which context was indicated in the first question, to account for participants who were not engaging in SB in the moment of the measurement. As in the framework, each type of SB could then be coded as either mentally active or passive. In the end, this short part of the questionnaire enabled to gain knowledge about, both, the context and type of participants' SB throughout the day.

**2.4 Procedure**

The previously described measurements were programmed in Ethica and pilot tested for three days. Afterwards, the study was shared with participants via the SONA system, email, or text messages. In all three recruiting methods, participants received a description of the study, instructions on how to download Ethica, a link to the specific Ethica study, and a code to the study (1730) as an alternative for the link. This way, participants could register in Ethica and sign up for this study using the code or the link.

Once participants signed up, they were again presented with the outline of the study within Ethica to ensure that participants who signed up via snowball-sampling were informed correctly. Next, participants were asked to give their informed consent. If participants did not give their consent, the study ended at this point and no data was saved. If participants gave their active consent, the data collection started right away (see Figure 2).

Immediately after consenting, participants were presented with the first questionnaire. This questionnaire assessed participants' *demographic information* and asked additional questions on thoughts that were relevant for another research project. Once this first questionnaire was answered, all activities for day one were finished. On the following days, each measurement was presented to participants in random intervals within the timeframes of 10:00 – 13:00 and 17:00 – 20:00 over the course of one week. While this time-dependent randomization of measurements increases the burden on participants, it also entails advantages that are important when measuring psychological experiences like mood (Barrett & Barrett, 2001). If participants are asked to answer the surveys at fixed times, it is possible that their daily routine influences their mood measures systematically. For example, measuring mood continually at 12 am could pair up with participants' lunch breaks and might, therefore, lead to a higher mood. Additionally, participants can anticipate the next measurement and prepare for the upcoming prompt, resulting in recall biases (van Roekel et al., 2019. This systematic distortion was tackled through the random measurement points. Moreover, the time frames have

been selected so that the target group is awake during the measuring, and that measurements are not too close to each other (Connor & Lehman, 2012). For each of the measurements, a reminder was set after 30 minutes to support participants' compliance (Yearick, 2017). Another 30 minutes later, the measurement point was closed and saved as missing data if participants had not responded.

On day two, participants answered a short survey on *mood* and *context and type* within both time frames (see Figure 2). From day three to eight, *sedentary time* was additionally assessed in the first time frame to measure the total sitting time of the previous day. For this reason, *sedentary time* alone was also measured one last time on day nine. This way, it was able to progressively measure students' mood and sedentary behaviour over the course of one week.

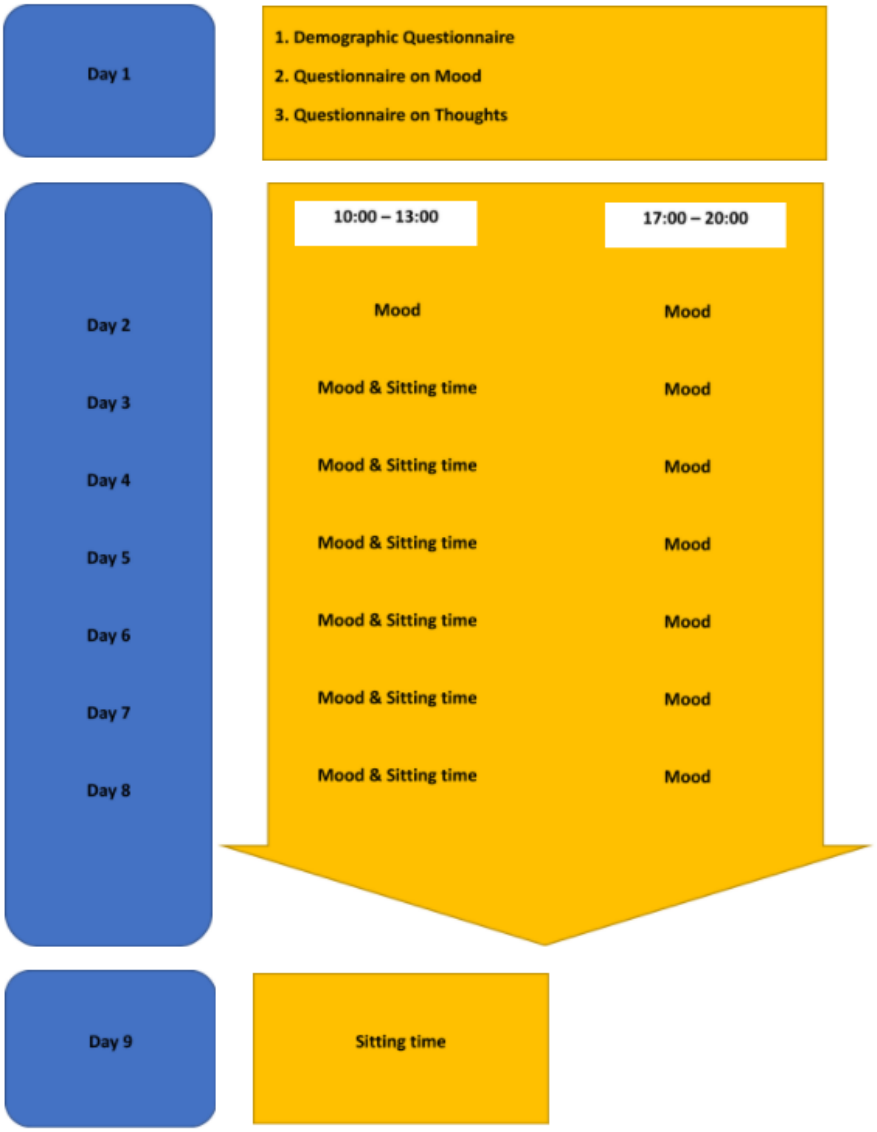


*Figure 2.* Timeline of subsequent measurements.

### 2.5 Data Analysis

The data from each created questionnaire was exported from Ethica in the form of CSV files. This data was imported in Excel to transform string data from the CSV files into numerical data. From here, each file was then imported in IBM SPSS Statistics 23 for statistical analysis. Except for the questionnaire on demographic data, all data files were merged into a single, comprehensive data set that was used to analyse the research questions of this study.

In SPSS, string data that was left from the Excel file was coded into numeric data (e.g., "4-quite a bit" → "4"). Next, the remaining data was cleaned. Unnecessary variables were deleted and participants with a response rate lower than 50% were removed from the dataset which is a common practice in ESM research (Connor & Lehman, 2012; Kang, 2013). In some cases, the data from the variable *sitting time* was corrected if a misunderstanding for apparent. That is, sometimes it was clear that participants have reported sitting time in hours instead of minutes. Only if this error was consistent over time, the data was calculated into the correct measurement unit (e.g., 5h → 300min).

After this, the final variables for further analyses were calculated in long format. First, the sum scores for PA and NA were calculated from the items of the I-PANAS-SF. Then, NA was subtracted from PA to obtain the variable *state mood* that represented participants' overall mood and is calculated similarly in the PANAS and I-PANAS-IF (Thompson, 2007; Watson et al., 1988). Next, total *sitting time* was calculated by adding the items from the PAST-U. Importantly, the PAST-U measured the sitting time of the previous day, while the momentary assessments examined current state measures. For example, the total sitting time of day three was measured on day four whereas state mood, context, and type of SB were measured on day three. To account for this temporal distortion, the *sitting time* was time lagged and, therefore, moved backwards by one day to match the correct momentary assessments. Since the variables context, mental activeness, and state mood were measured twice a day, each value for daily sitting time was then duplicated. As a result, the data set contained 14 measurements per participant whereby the daily sitting time matched the two momentary assessments of the same day.

Lastly, the items about the *context* and *mental activeness* were coded into dichotomous variables. For this, the examples from the framework that was proposed by Hallgren et al. (2020a) were coded into the according categories. As a result, each momentary assessment of SB could be categorized to be in the context of "occupation", "leisure", or "transport" and as either mentally "active" or "passive". Additionally, participants were given the option to not be

sitting in the moment of measurement. These instances were also coded as missing data for the variables *context* and *mental activeness*.

To analyse the hierarchal data from this study, a series of linear mixed models (LMM) with an autoregressive covariance structure were conducted. This was done because LMMs account for the nested data structure of ESM as well as for missing data (Magezi, 2015). The LMM handles missing data through the calculation of estimated marginal means (EMM) and can, thus, estimate participants' most likely behaviour based on their data. The EMMs were also used to investigate the fluctuations of state mood and sitting time between participants and over time points. For both options, the changes were visualised in a graph. Additionally, four individual cases were selected for supplementary visualization to further investigate the variability of the studied variables. Therefore, the variables *sitting time*, *context*, *mental activeness*, and *state mood* were visualized in a graph for these participants.

Furthermore, LMMs were used to test the three hypotheses of this study. For this, the participant number (*ID*) was used to account for nested data and the 14 timepoints were used to account for the longitudinal structure of the data. For all 3 models, *state mood* was set as the dependent variable. For all analyses, the estimates were unstandardized and a significance level of .05 was used (Lehmann, 1958). In the first model, *sitting time* was added as a fixed covariate to analyse its effect on state mood. For the second model, the dichotomous variable *context* was added as a factor, including the interaction effect with *sitting time* to test the hypothesized moderation effect. In the third model, the dichotomous variable *mental activeness* was introduced similarly to test for its moderation effect. Lastly, Microsoft Excel was used to visualize the results as line graphs and bar charts.

## 3. Results

### 3.1 Participant Characteristics

#### *3.1.1 Sociodemographic Characteristics*

The original sample consisted of 38 participants. From that, four participants were excluded due to a response rate below 50% (Connor & Lehman, 2012), resulting in a final sample size of $N$=34 (see Table 1). Participants were primarily female (76,5%) and German (88,2%). In the sample, 33 of the participants were university students, only 1 person was a student of higher education. The age ranged between 19 and 29 ($M_{age}$ = 22.38, $SD_{age}$ = 2.20).

In the adjusted sample, the overall response rate was 81.9%, resulting in 388 out of 474 measurement points. Five participants had a response rate of 100% that allowed for later individual visualisations of the investigated variables

**Table 1**

*Sample Characteristics (N=34)*

| Characteristics | *n* | % |
|---|---|---|
| Gender | | |
| Female | 26 | 76.5 |
| Male | 8 | 23.5 |
| Nationality | | |
| German | 30 | 88.2 |
| Dutch | 3 | 8.8 |
| Other | 1 | 2.9 |
| Occupation | | |
| University student | 33 | 97.1 |
| Other higher education | 1 | 2.9 |

### *3.1.2 Sedentary Time and Factors of Sedentary Behaviour*

Table 2 displays the characteristics of students' SB in this sample. Students' mean sedentary time was 565 minutes per day (equalling to 9.43h, *SD* = 3.57). Further, the median in this sample was 559.5 minutes per day (*IQR* = 283.76). Thus, despite the large standard variation, the data about daily sitting time was not skewed. This sample mean is not uncommon given the original validation study of the PAST-U, where students' mean sedentary time was 10.72h (*SD* = 2.04; Clark et al., 2016). Comparably, university students in this sample sat about an hour less on average but sitting time varied more strongly among different participants. In sum, the university students in this study represented a highly sedentary subgroup of the young adult population in which sitting time differed quite strongly between participants.

Next, the additional factors *context* and *mental activeness* during sedentary behaviour have been reported by participants (see Table 2). During the ESM measurements, 41% of the time students were in the context of occupation, and 59% in the context of leisure.[1] Additionally, 53% of the SB was found the be mentally active in the moment of measurement,

[1] Please note, that in this sample only in 14 out of 388 measurement points, participants have reported to be in the context of transport. Therefore, these data points and the variable "transport" have been excluded from most analyses, resulting in 374 data points.

and 22% was mentally passive. Moreover, 25% of the time, students reported that they were not sitting during the moment of the measurement. Excluding this third option, students engaged to 70% in active SB and to 30% in passive SB. To conclude, university students in this sample engaged in more SB in the context of leisure and overall SB was more often mentally active.

**Table 2**

*Sedentary Time, Context, Mental Activeness, and State Mood among Dutch University Students (N=34; Number of measurement points=374)*

| Variables | *M* | *SD* | Range | Frequency | % |
|---|---|---|---|---|---|
| Daily sedentary time | 565.65 | 214.16 | 1170 – 95 | | |
| Context | | | | | |
| Occupation | | | | 154 | 41.2 |
| Leisure | | | | 220 | 58.8 |
| Mental activeness | | | | | |
| Active | | | | 197 | 52.7 |
| Passive | | | | 84 | 22.5 |
| Not sitting | | | | 93 | 24.9 |
| State mood | 4.20 | 3.31 | -7 – 12 | | |
| State PA | 8.55 | 2.54 | 3 – 15 | | |
| State NA | 4.33 | 1.96 | 3 – 13 | | |

### *3.1.3 Mood*

Table 2 also displays the mood scores of participants. The mean state mood in this sample was 4.30 (*SD* = 3.31). This score was obtained by subtracting the state NA sum score (*M* = 4.33, *SD* = 1.96) from the state PA sum score (*M* = 8.55, *SD* = 2.54). Each of these sum score could range from 3 to 15, resulting in a final state mood score that could range from -12 to 12. In sum, the state positive affect reported by students was roughly twice as high as the state negative affect, leading to a state mood that was about 4 points above the scale's centre. This implies that state mood was overall more positive within this sample.

## 3.2 Visual Analyses: Variations of Sitting Time and Mood

### *3.2.1 Means of Sitting Time and Mood per Day*

Figure 3 displays the EMM scores of sitting time and state mood over time. Over a period of one week, with two measurements per day, the EMM for state mood varied relatively little within this sample. State mood was the lowest at the first measurement of day 6 (Timepoint 11) with a score of 3.32 and the highest at the first measurement of day 5 (Timepoint 9) with a score of 4.78. Given that the 24-point range of this scale, this variation is relatively small. Overall, the EMMs for state mood did not deviate strongly from the mean state mood of $M$ = 4.20 that has been reported previously.

Moreover, the EMMs for sitting time did also not fluctuate strongly over time within this sample. Sitting time was the lowest at timepoint 12 with 552 minutes and the highest at timepoint 7 with 588 minutes. Apart from that, sitting times per timepoint fit into this 30-minute range. Based on the graph, it is not apparent that changes in sitting time and mood over time are in accordance with each other.

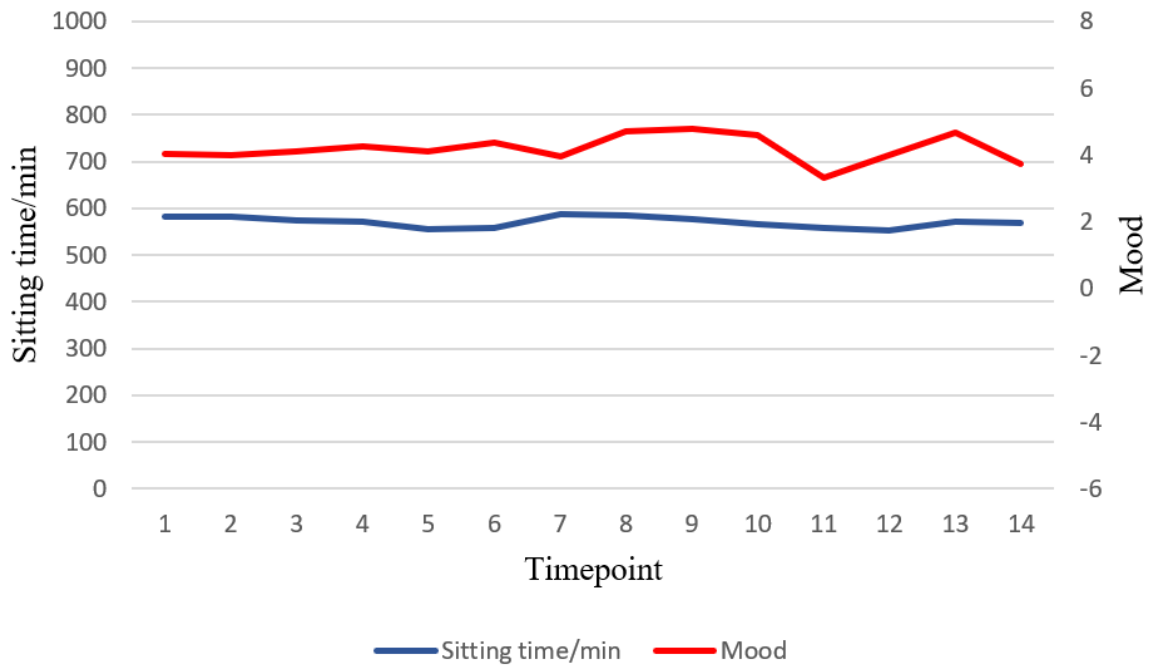


*Figure 3*. Estimated marginal means of sitting time and mood over all 14 measurement points

### *3.2.2 Means of Sitting Time and Mood per Participant*

Figure 4 demonstrates the EMM scores of sitting time and mood per participant. Considering the comparably small fluctuation of mean sitting time and mood over time, this graphic demonstrates a much larger variation of these variables between participants. Mean

sitting time ranged from 230 minutes for participant 17 to 855 minutes for participant 7. In total, four participants had a mean sitting time below 400 min per day, while four other participants sat for more than 700 minutes per day on average. From this figure, it is visible that the daily mean sitting time over one week varied strongly between different university students. This finding also resembles the large standard deviation that was found for daily sitting time ($SD$ = 214.16).

Similarly, average mood varied strongly between students during the measurement period. In total, five participants had an average mood score below 2. On the other hand, five participants also experienced an average mood of 7 or higher. Notably, the participants 3 and 13 had the lowest average mood scores with 0.41 and 0.56 whereas participant 25 had a particularly high mean mood score of 9.29. As with the association between sitting time and mood over time, no clear connection between these variables is visible between participants. For example, participants 2, 4, and 13 have been sitting comparably long with EMM around 700 minutes per day. However, there are large differences in their experienced mood ranging from 0.56 to 3.30 and 5.57. Simultaneously, those who had an average mood score that is comparable to the mean score with the entire sample ($M$ = 4.20) had mean sitting times ranging from 244 to 883 minutes. After all, a clear relationship between sitting time and mood was not apparent in the comparison of different participants. Instead, sitting time and mood, as well as their relation to each other, varied strongly between students.

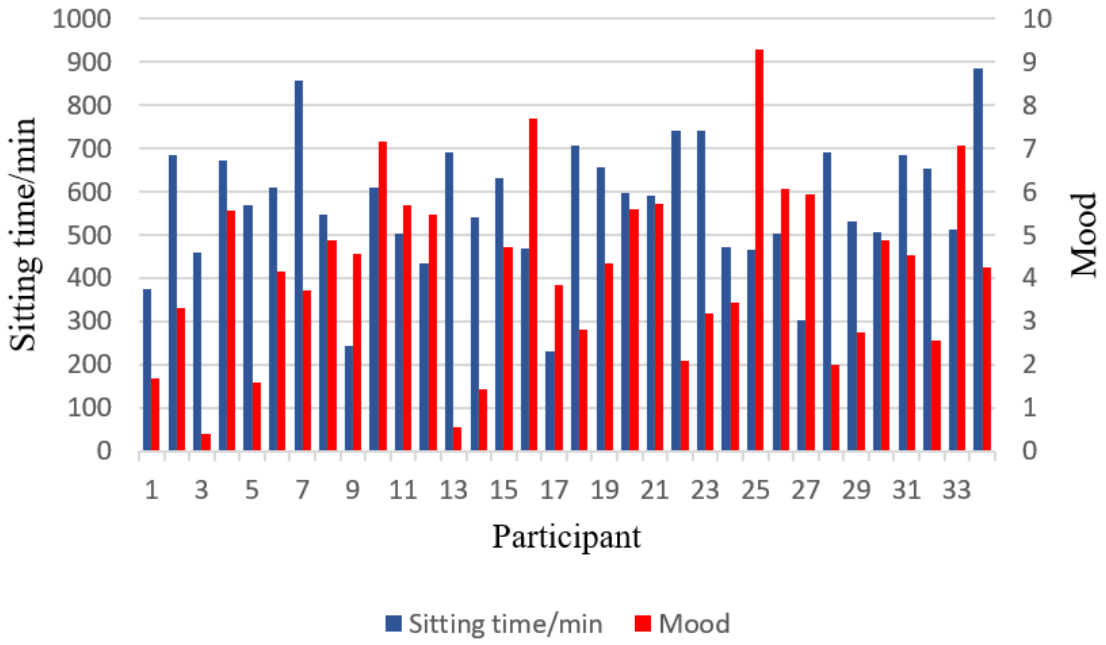


*Figure 4*. Estimated marginal means of sitting time and mood for all 34 participants

### *3.2.3 Individual Visualisation*

For individual visualisations, daily sitting time was displayed over the course of one week over 14 measurement points. In this, two equal bars are referring to the same day, whereby the first bar represents the first daily measurement between 10:00 to 13:00 and the second bar represents the second daily measurement between 17:00 and 20:00. For each of these measurement moments, the dichotomous variables *context* and *mental activeness*, as well as *state mood*, can be read from the graphics. This representation of the data allowed to visualize the temporal variation and relationship of all the investigated variables. The participant numbers are consistent throughout the text and can therefore be compared to the sample characteristics (see Figure 4).

**3.2.3.1 Participant 24.** Figure 5 represents the individual data of participant 24. Most apparent, the participant's daily sitting time was very stable over the course of the week with values closely gathering around 7.5 hours per day. This amount of sitting does not deviate strongly from the average sitting time that was found within the sample ($M = 9.42$, $SD = 3.57$). In comparison, state mood also resembles the mean found in the sample ($M = 4.20$, $SD = 3.31$), ranging from 0 to 7. Moreover, this participant sat relatively equally in the contexts of occupation and leisure and engaged in more mentally active SB, resembling the general frequency of these confounding variables within the sample. It is noticeable though, that the participant exclusively engaged in mentally active SB in the context of occupation, and exclusively in mentally passive SB during leisure. Overall, this participant can be said to be representative of the average numbers found in this sample.

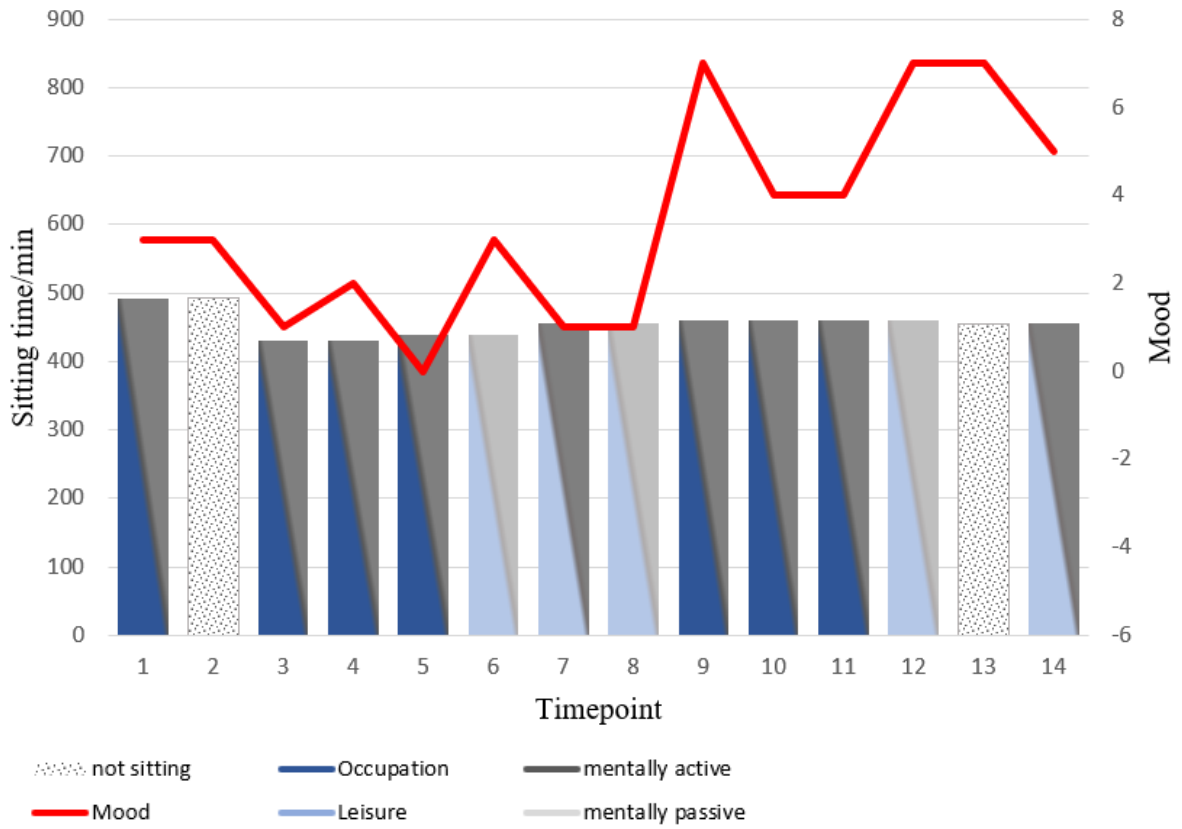


*Figure 5.* Sitting time, context, mental activeness, and state mood of Participant 24

**3.2.3.2 Participant 32.** The data of participant 32 is displayed in Figure 6. This participant has mostly been sitting between 10 and 13.5 hours per day. On day one, the participant has reported a comparably low sitting time of approximately 5 hours and experienced comparably higher state mood indicated by scores of 5 and 6. The next day, sitting time increased rapidly above 13.5 hours and the mood score decreased strongly to -5. Apart from this instance, sitting time and state mood did not vary in clear relation to each other. However, mood was lower on the first measurement of each day except for day seven. This implies that the participant's mood was worse at the beginning of each day and increased as the day progressed.

In general, this participant's overall sitting time and perceived mood are also in line with the general numbers found in the sample. However, compared participant 24, this participant experienced stronger fluctuations in, both, sitting time and state mood.

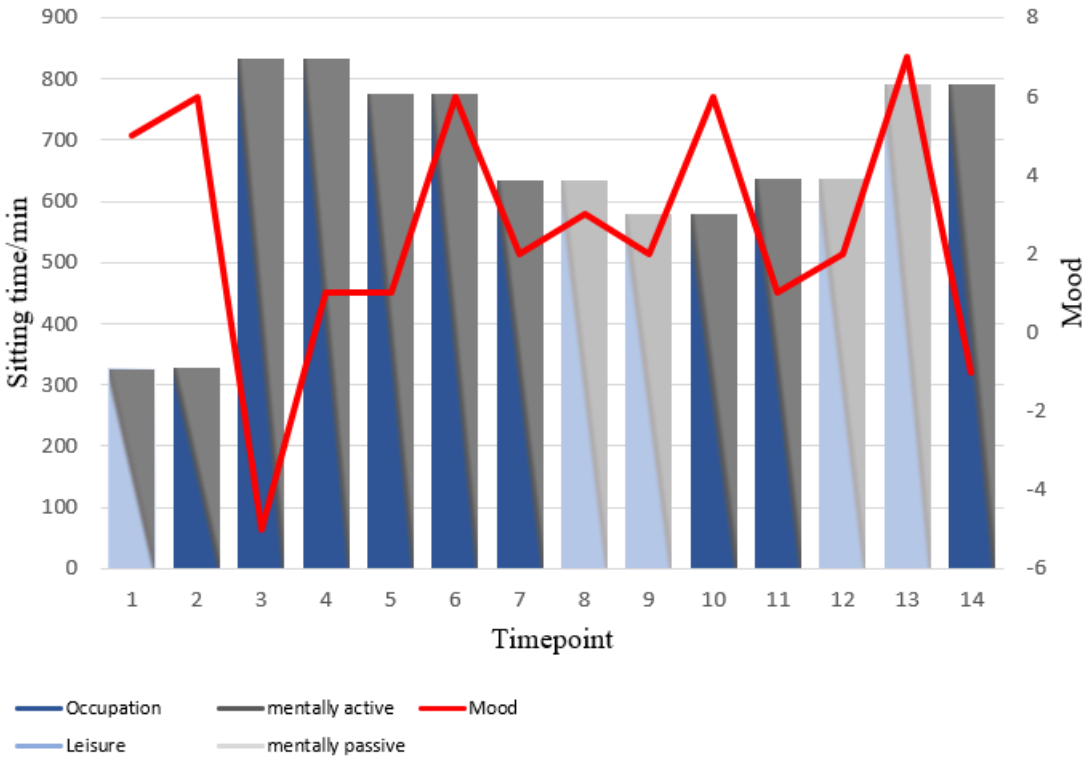


*Figure 6.* Sitting time, context, mental activeness, and state mood of Participant 32

**3.2.3.3 Participant 7.** Within the sample, participant 7 has reported the second highest sitting time (see Figure 7, see also Figure 4). On day six, sitting time was the highest with 19.5 hours. Overall, sitting time mostly fluctuated between 13.5 and 16.5 hours with a comparably little sitting at day one. Despite this large amount of sitting, state mood was representative of the sample mean and stable with values gathering around 4, ranging from 2 to 6. Interestingly, this participant sat almost exclusively in the context of leisure. But compared to the last two visualized participants, this student has been engaging in a lot of active SB during leisure.

With regard to the sample characteristics, this participant resembles a more extreme case. In fact, given the distribution of sitting time in the sample, this participant was found to be an outlier. At the same time, the participants' mood resembled the sample mean well and was comparably stable over time. Compared to previous cases, this participant constitutes a student who was highly sedentary but who's mood, context, and mental activeness were stable over time.

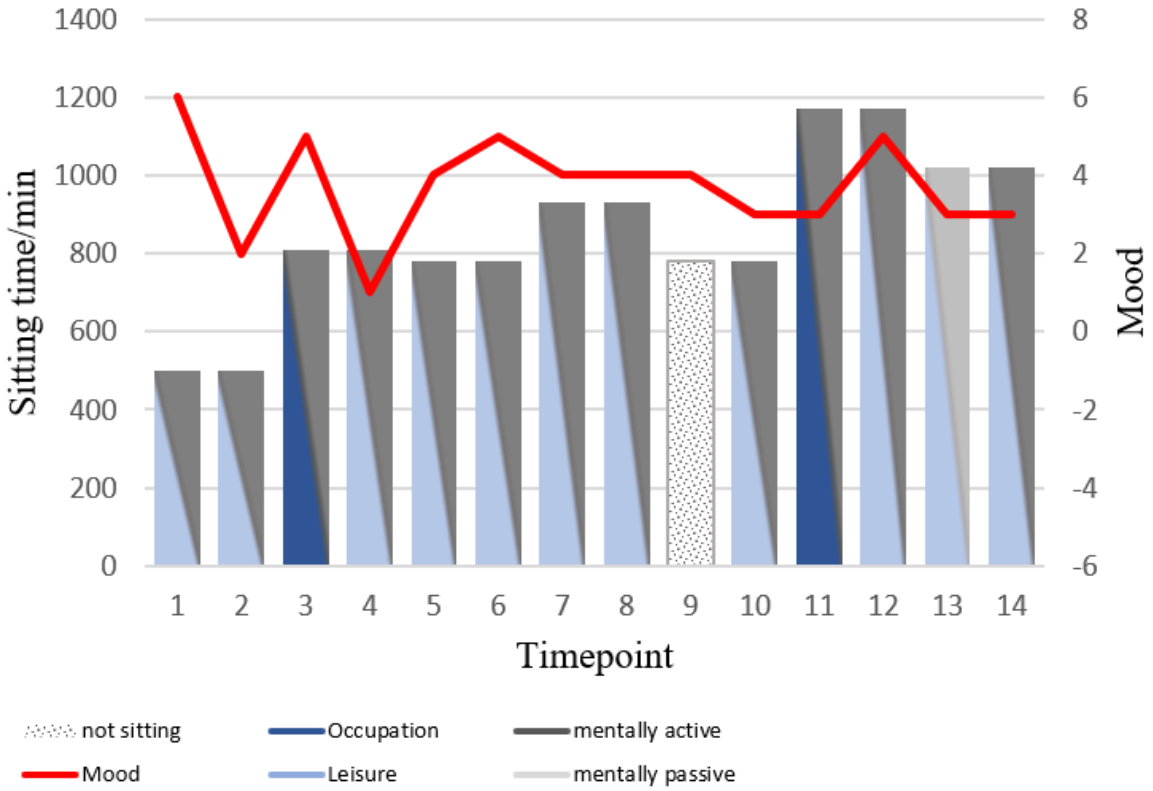


*Figure 7.* Sitting time, context, mental activeness, and state mood of Participant 7

**3.2.3.4 Participant 9.** Figure 8 shows the individual data of participant 9. In contrast to the previous examples, this participant sat very little with more stable daily sitting times between 3.5 and 5 hours per day. However, experienced state mood fluctuated strongly ranging from -3 to 9. While the frequency of different contexts and mental activeness varied relatively equally, it is interesting that this participant was often not sitting at all in the moment of the measurement. Unfortunately, the sitting time for the last day was not measured. To conclude, this participant has reported low levels of daily sitting that did not vary strongly but has experienced strong changes in state mood.

In relation to the sample characteristics, this participant constitutes another extreme that is opposing to the characteristics of participant 7. Specifically, this participant continuously sat very little, but experienced much larger changes in mood over time.

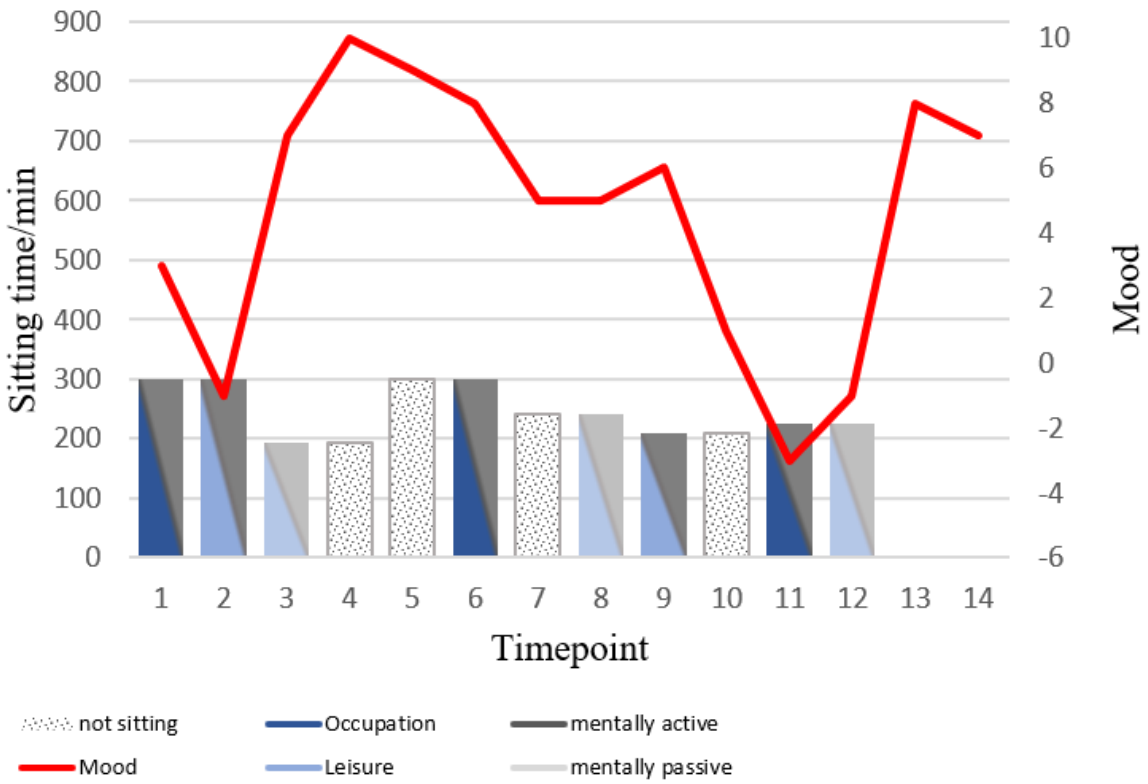


*Figure 8.* Sitting time, context, mental activeness, and state mood of Participant 9

**3.2.3.5 Conclusion.** Based on the visual analyses of the individual cases it became apparent that university students in this sample varied strongly in their daily sitting times and their state mood which was already visible in Figure 4. But importantly, the temporal stability of these aspects also differed between participants. For example, participant 24 and 32 both fit the overall sample characteristics but participant 32 experienced much larger fluctuations in daily sitting time and mood during the week. Emphasizing this individuality, the participants 7 and 9 showed even stronger differences between their profiles. Participant 7 sat a lot during the week with large differences between days but experienced a rather stable mood, whereas participant 9 continuously sat very little and but experienced large changes in mood. In sum, it was visible that participants differed in the consistency of their daily sitting time and that some students experienced larger fluctuations in mood during this period.

Furthermore, the cases showed participants had unique profiles such as participant 32 whose mood increases as days progressed or participant 7 who engaged almost only in mentally active SB and during leisure. Despite these individual patters and large differences between participants, no clear relationships were visible between variables. Therefore, further statistical analyses were conducted to answer the proposed hypotheses and investigate possible associations between students' SB and their mood.

### 3.3 Inferential Statistics

To analyse the effect of sitting time, as well as the influence of context and mental activeness, on state mood, three different linear mixed models were run (see Table 3). For the first model, no significant effect of sitting time on mood was found [$B = 0.002$, $SE = 0.001$, $F(1, 225) = 2.87$, $p = .091$]. Therefore, *H1* was rejected.

The second model revealed no significant effect of context on mood [$B = 0.385$, $SE = 0.946$, $F(1, 273) = 0.166$, $p = .684$]. Further, no significant moderation effect of context on the relationship between sitting time and mood was identified [$B < 0.001$, $SE = 0.001$, $F(1, 267) < 0.01$, $p = .996$]. Therefore, *H2* was also rejected.

In the third model, mental activeness did not significantly affect mood [$B = -0.262$, $SE = 1.157$, $F(1, 213) = 0.51$, $p = .821$]. Also, no significant moderation effect of mental activeness on the relationship between sitting time and mood was found [$B = 0.002$, $SE = 0.02$, $F(1, 210) = 0.77$, $p = .381$]. Therefore, *H3* was rejected.

Lastly, a Wald Z test has revealed a significant random intercept for participant ID for all three models ($p = .004$, $p = .006$, $p = .004$), indicating that a significant proportion of variance was explained by the participant factor within the models.

**Table 3**

*Linear Mixed Models for Fixed Effects for the Variables State Mood, Sitting Time, Context, and Mental Activeness*

| Variable | *B* | *SE* | CI | *p* |
|---|---|---|---|---|
| Model 1 | | | | |
| Intercept | 5.113 | 0.675 | [3.778, 6.450] | **<.001** |
| Sitting time | -0.002 | 0.001 | [-0.004, 0.001] | .091 |
| Model 2 | | | | |
| Intercept | 5.079 | 0.760 | [3.578, 6.580] | **<.001** |
| Sitting time | -0.002 | 0.001 | [-0.004, 0.001] | .115 |
| Context | 0.385 | 0.946 | [-1.479, 2.249] | .684 |
| Sitting time x context | <0.001 | 0.001 | [-0.003, 0.003] | .996 |
| Model 3 | | | | |
| Intercept | 4.694 | 1.096 | [2.533, 6.854] | **<.001** |
| Sitting time | -0.003 | 0.001 | [-0.006, 0.001] | .156 |
| Mental activeness | -0.262 | 1.156 | [-2.541, 2.017] | .821 |
| Sitting time x mental activeness | 0.002 | 0.002 | [-0.002, 0.005] | .381 |

*Note*. Dependent variable: State mood.

## 4. Discussion

The current study was conducted to investigate the relationship between SB and mood among Dutch university students. More specifically, it was examined how the context and type of SB were associated with state mood. To our knowledge, this was the first study to measure university students' engagement in mentally active and passive SB within the contexts of occupation or leisure, and the first to investigate the influence of these factors on students' mood. The findings indicate that students in this sample were highly sedentary, mostly mentally active and during leisure, and perceived more positive than negative mood. Further, it was found that all these aspects varied quite strongly between students and over time. However, no relationships between sitting time, context or type of SB, and state mood were found. The results from this study contribute to the ongoing research about the relationship between SB and mood and emphasize individual differences in confounding factors like context or mental activeness.

### 4.1 Sitting Time

The results indicated that the investigated Dutch university students were highly sedentary in times of the COVID-19 regulations. Overall, participants in this sample have reported to sit 9.4 hours on average per day. This finding can be compared to a recent meta-analysis on university students' sitting times by Castro et al. (2020) who found an average sitting time of 7.3 hours assessed through self-report questionnaires. Importantly, the authors noted that most of the included studies measured sitting time through single-item questionnaires, mostly the IPAQ. These short questionnaires are known to underestimate self-reported sitting time compared to multi-item questionnaires like the PAST-U that was used in this study (Prince et al., 2020). Therefore, it can be concluded that the use of different measurements might partly explain the higher average sitting time that was found in the sample. Still, compared to most studies that were included in the meta-analysis by Castro et al. (2020), students' sitting time was more than two hours higher in this sample (e.g., Farinola & Bazán, 2011; Moulin & Irwin, 2017). Given this large deviation, it is possible that the difference in sitting times is not only due to the use of a different measurements but that students in this sample have still engaged in particular high levels of SB.

In this case, it is likely that the high level of sitting in the studied sample was related to the living changes that have gone in hand with the COVID-19 regulations. Since the start of the pandemic, recent studies have observed increased sitting times among university students (Ammar et al., 2020; Bertrand et al., 2021; Romero-Blanco et al., 2020). The reason for the high levels of sitting of these studies may be explained by the multiple effects that the restrictions had on students' life. Overall, the pandemic has affected many factors that promote SB for students such as increased screen time (Bennasar-Veny et al., 2020), less social interaction (Sugiyama et al., 2021), more time spend at home (Ammar et al., 2020; Molina-García, Menescardi, Estevan, Martínez-Bello & Queralt, 2019), and the lack of class attendance and exams (Deliens et al., 2015). In sum, it seems that the COVID-19 regulations might have indirectly heightened SB among university students. The findings from the current study fit this high amount of sitting among university students during the pandemic as participants sat more than nine hours on average. These levels of sitting are alarming given that health risks like cardiovascular disease, type-2 diabetes, and all-cause mortality increase significantly at a threshold of 7 to 8 hours of daily sitting (Chau et al., 2013; Patterson et al., 2018). Therefore, interventions to reduce university students' SB are needed.

### 4.2 Relationships between SB and Mood

Next, the relationship between students' sitting time and their experienced mood was investigated. Firstly, the hypothesis that higher daily sitting time would be associated with decreased state mood was not confirmed. University students in this sample did not have worsened mood when they were sitting longer. This finding is in some contrast to the meta-analysis by Zhai et al. (2015) who have found a positive relationship in the pooled data of 24 studies. In their explanation for this finding, Zhai et al. (2015) mentioned two prominent accounts for the relationship between SB and depressive symptoms like mood: the displacement of physical activity through SB (Biddle & Asare, 2011) and the *social withdrawal hypothesis* (Kraut et al., 1988), which states that increased sitting time would keep individuals from interacting with other people. Based on this, the authors have concluded that highly sedentary individuals might engage in less physical activity or social interactions and are, therefore, more likely to be depressed.

Yet, the current study did not find a relationship between SB and mood. The reason for this might be connected to the sample that was researched during the COVID-19 pandemic. As described above, the regulations have influenced many aspects of students' life that are known to enhance SB (e.g., Ammar et al., 2020) and it seems that these limitations have made students' daily routine more restricted and repetitive during the pandemic. That is, students were mostly obligated to restrain from social interaction and most sport activities (Ministerie van Algemene Zaken, 2021). In line with this, people's physical activity and social interaction have decreased during COVID-19 (Calbi et al., 2021; Puccinelli et al., 2021; Robinson et al., 2021; Sugiyama et al., 2021). But against to the proposed explanation by Zhai et al. (2015), physical activity and social interactions had no longer been replaced by prolonged sitting as individuals did not have these opportunities anymore. Based on this, it is possible that increased SB has not affected students' experienced mood significantly in this study due to the impossibility to engage in other activities that would normally increase mood.

At the same time, the authors have emphasized that, despite the overall significant effect, many of the included studies did not find any relationships (Zhai et al., 2015). In line with this, the few studies that have also employed an ESM design to investigate the association between SB and mood have found mixed results. So far, Aggio and colleagues (2017) did also not find a relationship, while two other ESM studies identified significant associations between sitting time and mood (Elavsky, Kishida & Mogle, 2016; Giurgiu et al., 2019). Based on this, the lack of an association in current study is not generally unusual for research on SB and mood, which is why this study has further investigated possible moderation effects (Hallgren et al., 2020a).

Secondly, the influence of the context of students' SB on this relationship was examined. The results showed that students were more sedentary in the context of leisure (59%) than in the context of occupation (41%). Moreover, students almost never engaged in SB within the context of transport. The relatively large proportion of occupational sitting is not surprising given that students often engage in activities like studying or writing assignments that require prolonged sitting (Carballo-Fazanes et al., 2020; Cotten & Prapavessis, 2016). But against the second hypothesis, occupational sitting did not moderate the relationship between SB and mood. This finding opposes recent studies suggesting that sitting during occupation might affect mood positively while sitting during leisure would decrease mood (Hallgren et al., 2018; Hallgren et al., 2020a). A possible explanation why the context of SB did not affect students' mood in this study could be the ambiguity of contextual categories. First of all, the results showed that transportation was no longer necessary for students as physical presence at the university and social interactions had to be limited (Ministerie van Algemene Zaken, 2021). At the same time, the restrictions might have also blurred the contextual properties of the remaining two categories. Specifically, students had to study from home and could not visit other places like restaurants or cinemas during leisure. Consequently, the sedentary contexts of occupation and leisure would have merged into a united category as students had to stay at home during both periods. With regard to the momentary assessments of this study, participants might have answered to be sitting in the context of occupation in the morning and during leisure in the afternoon but, in fact, perceived no meaningful change in context at all. Therefore, it is possible that, in reality, students have experienced only small variation in the contexts that they were sitting in, which might explain why the context of SB did not affect their state mood in this study. At the same time, this implication would have also affected students' social interaction which supports that confounding role of the *social withdrawal hypothesis* was limited in this study. It is, therefore, important to investigate whether this finding holds true when students are again able to sit in different contexts and meet other people.

Lastly, the relationship between the type of students' SB, being either mentally active or passive, and students' mood was assessed. The findings showed that university students in the Netherlands engaged in more active (70%) than passive SB (30%). Compared to the general public, students in this sample have engaged in higher proportion of active SB. In a study that included over 15000 participants, Hallgren et al. (2019) have found that, on average, people engaged to 60% in active SB, and a similar ratio was found in a 13-year cohort study (Hallgren et al., 2018). But as this is the first study to examine the mental activeness of university students' SB, these results cannot be directly compared to other research that targeted this specific

subgroup. However, previous studies have investigated common SBs of university students. In this regard, it has been found that students spent the most time sitting while studying, talking to others, reading, and while using the computer or other screen-based devices (Carballo-Fazanes et al., 2020; Peterson, Sirard, Kulbok, DeBoer & Erickson, 2018; Rouse & Biddle, 2010). Based on the categorisation that was proposed by Hallgren et al. (2020a), these SBs are classified as mentally active. Other less prominent SB among university students include watching television or "hanging out" (Carballo-Fazanes et al., 2020; Rouse & Biddle, 2010), which are classified as mentally passive (Hallgren et al., 2020a). Therefore, it comes as no surprise that the university students engaged in more active SB, especially during the measurement times that fall into the common working time.

However, the hypothesis that mentally active SB would decrease a negative association between sitting time and state mood was not confirmed. This finding opposes the results of previous studies which have argued that the concentration that is required during active SB might increase mood, and therefore, protect from the development of depressive symptoms like decreased mood (Hallgren et al., 2018; Hallgren et al., 2020b; Kikuchi et al., 2014). Such a protective effect of mental activeness on the relationship between SB and mood was not identified in this study. This being said, it should be emphasized that the sample characteristics of the studied target group are important to consider. University students in this sample have generally engaged in much more active SB, also during leisure. It thus is apparent that, despite the current pandemic and the resulting consequences on people's lives, students constitute a highly mentally active subgroup of the sitting population. Based on this and the propositions of a protective effect of mentally active SB (Hallgren et al., 2018; Hallgren et al., 2020b), it might be possible that the high level of active SB has protected students from negative mood changes. An example of this would be the visual analysis of participant 7, who had the second highest sitting times within the sample but almost exclusively engaged in mentally active SB and experienced a stable mood that fit the sample mean. However, this analysis is not evidential and the proposition of such a protective effect has not been established yet. Hence, it remains hypothetical if this floor effect has really preserved students from negative mood consequences in this study and, thereby, lead to the absence of relationships between SB and mood. Therefore, research that compares a highly mentally active sedentary subgroup, like students, with a more mentally passive subgroup is needed to examine whether a high ratio of active SB protects individuals from decreased mood.

### 4.3 Strengths and Limitations

The strength of this study is its progressive contribution to the recent developments in this research domain. More specifically, the study has followed the demand for new measurements in SB research (Zhai et al., 2015), and the call for contextual measurements of students' SB to assess specific determinants (Castro, Bennie, Vergeer, Bosselut, & Biddle, 2018). In this, the study has built upon a newly proposed framework to further improve the understanding of the association between the type of SB and mood changes (Hallgren et al., 2020a). In combination, the study design has allowed to examine these new characteristics of SB on an individual level in a longitudinal matter. As a result, the temporal development of these characteristics could be visualized and compared between participants.

At the same time, the study design also poses the largest limitation to this study. Due to time constraints, this study measured sitting times of the previous day and could only assess momentary state mood twice per day. Other studies were able to employ a more deliberate operationalization compared to this study. For example, Giurgiu et al. (2019) measured sitting time during the same day by the means of accelerometers instead of a self-report questionnaire. Additionally, state mood was measured 10 times a day with up to 50 data points per participant. This data allowed to compare sitting time and mood in closer temporal dependency and identify effect sizes within smaller timeframes (Giurgiu et al., 2019). It is, thus, possible that a more detailed measurement like this would have yielded a comparable association between sitting time and mood. Yet, the implementation of accelerometers was not applicable due to the Covid-19 pandemic, and the use of self-report questionnaires in this study allowed to additionally examine the influence of contexts and types of SB (Prince et al., 2020).

Lastly, it is important to mention that the timepoints in this study referred to subsequent days but did not necessarily correspond with specific days of the week because participants have started to answer the questionnaires on different days. Therefore, no interpretations about the influence of weekdays can be made. This aspect is important to consider as recent studies have found variations in university students' SB and physical activity during the week (Castro et al., 2018; Rouse, & Biddle, 2010). Further, the daily time of measurements are important to consider as mood, especially PA, is found to increase in the afternoon (Hedges, Jandorf, & Stone, 1985). This trend has been also resembled by the visual analysis of participant 32 who consistently experienced better mood during the second daily measurements. Therefore, future studies should account for, both, week and day progression in their measurements.

### 4.4 Implication for Future Research

Further research is needed for a more nuanced understanding of the moderating factors that could affect the relationship between SB and mood. Thereby, upcoming studies should build upon the limitations of this study. Once possible again, sitting time should be measured objectively through accelerometers. In combination, the type of SB could also be measured objectively due to the progression of unobtrusive physiological measurements of mental workload (Charles & Nixon, 2019; Nixon & Charles 2017). This way, sitting time and the mental activeness during that sitting can be assessed objectively throughout the day. Future ESM studies that employ such these physiological measurements should measure mood so in short intervals to identify more subtle effects (Giurgiu et al., 2019). Lastly, a study that combines these implications would need to be employed in a fixed and structured timeframe to account for confounding factors like week and day progression or social interactions.

After all, the findings from this study have demonstrated the complexity of the relationship between SB and mood and the importance of individual characteristics. Through a combination of these proposed recommendations, it can be possible to get a better understanding of the variations in the context and type of SB and investigate their relationship with mood in more detail.

References

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# Appendices

## Appendix A

***Informed Consent***

---

Dear participant,

Thank you for taking part in our study!

Here is some practical information for you to know about this study:

For you to participate, you need to be at least 18 years old, have a smartphone with Android or iOS, and a proficient understanding of the English language.

During the study:

We are interested in the relationship between sitting behaviour and mood. Also, we are going to look into possible influences on this relationship, such as your activity and thoughts at the time. For that, you will fill out multiple questionnaires.

1. On the day of signing up, so on day one, you will complete a demographic questionnaire, as well as two questionnaires, one on your mood and one on your thoughts. Together, this will take approximately 10 minutes.
2. Starting from the next day, so on day two, you will fill out two short questionnaires a day that will take about 3 minutes to complete. You will receive a notification on your phone when it is time to complete the survey. These notifications will appear randomly within the time frames of 10:00 - 13:00 and 17:00 - 20:00. You will receive a reminder after 30 minutes. One hour after receiving the prompt, the questionnaire will be no longer available. If you miss a measurement, don't worry but please continue with the study and try to be consistent :)
3. From day three to day eight, you will fill out a somewhat longer questionnaire of 8 minutes once a day together with your morning prompt that measures your sitting behaviour from the day before. On day nine in the morning, you will fill out the last questionnaire on your sitting behaviour for day eight.

We kindly ask you to complete the following steps before you can start the study:

- Please follow this link https://ethicadata.com/study/1730/ and click on 'Participate'.
- Please download the application "Ethica" from your App or Google Play Store and log in with the account you created. If the App or Google Play Store does not automatically open, use the following links:
    - Google Play Store: https://play.google.com/store/apps/details?id=com.ethica.logger&hl=en&gl=US
    - App Store: https://apps.apple.com/ca/app/ethica/id1137173052
- Create an account as a participant (or log in if you already have a participant account).
- Make sure to enable the notifications for Ethica as instructed.
- Read the terms and conditions carefully and agree to join the study (You can also join the study with the registration code 1730).
- Follow the instructions as provided throughout the next days.

The data gathered will be used solely for the purpose of this study. Ethica will generate participant IDs upon registering, meaning that the data will be anonymised. Your name and email address is stored on the Ethica database. You have access to your own data via your online account as well as have the right to delete your data at any time. This means that your name and email address are stored separately from your survey answers. The researchers only have access to the content of your surveys as well as your participant ID. You can withdraw from the study at any time, without providing a reason for doing so.
This study has been reviewed and approved by the Ethics Committee. No risks can be expected from taking part in this study. You may become increasingly aware of your mood, thoughts and behaviour which could potentially lead to discomfort in some people.

For further information, or in case of any questions, the researchers involved can be contacted via email:

If you have any 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 researchers, please contact the Secretary of the Ethics Committee of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-bms@utwente.nl

Hereby, I declare that I am 18 years or older. I have read and understood the information provided, or it has been read to me. I consent voluntarily to participate in this study and understood that I can refuse to answer questions, and I can withdraw from the study at any time, without have to give a reason.

☐ I consent.

☐ I do not consent (in this case, the study will end at this point).

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**Appendix B**

***Item List of the Comprehensive Questionnaire***

| **Baseline Questionnaire** | Question | Answer Options |
|---|---|---|
| Demographics | | |
| Item 1 | "*How old are you?*" | Numeric value |
| Item 2 | "W*hat is your occupation?*" | 1) Student (University)<br>2) Student (Higher education)<br>3) Other |
| Item 3 | "*What is your gender?*" | 1) Female<br>2) Male<br>3) Other<br>4) Prefer not to say |
| Item 4 | "*What is your nationality?*" | 1) German<br>2) Dutch<br>3) Other |

| **ESM Questionnaire** | Question | Answer Options |
|---|---|---|
| State Mood | | |
| Item 1 (NA) | "*Right now, to what extent do you feel upset?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |
| Item 2 (NA) | "*Right now, to what extent do you feel afraid?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |
| Item 3 (NA) | "*Right now, to what extent do you feel nervous?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |
| Item 4 (PA) | "*Right now,to what extent do you feel active?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |

| | | |
|---|---|---|
| Item 5 (PA) | "*Right now, to what extent do you feel attentive?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |
| Item 6 (PA) | "*Right now, to what extent do you feel determined?*" | 1) very slightly, or not at all<br>2) a little<br>3) moderately<br>4) quite a bit<br>5) extremely |
| Context | | |
| Item 1 | "*Right now, what context are you in?*" | 1) Occupation/Study<br>2) Leisure<br>3) Transport |
| Type | | |
| Item 1.1 (Follow-up "*Occupation*") | "*What were you doing right before you started answering this survey?*" | 1) Sitting and using the computer for work or study purposes<br>2) Sitting while participating in a meeting<br>3) Sitting while performing other tasks that require problem solving or mental effort<br>4) Not sitting |
| Item 1.2 (Follow-up "*Leisure*") | "*What were you doing right before you started answering this survey?*" | 1) Sitting or lying while watching TV, or watching a movie, YouTube, etc. on your laptop or smartphone<br>2) Sitting or lying while listening to music<br>3) Sitting or lying for rest but not sleeping<br>4) Sitting or lying while reading (paper or electronic format)<br>5) Sitting or lying while playing a game (computer games, board games, crossword puzzles, etc.)<br>6) Sitting or lying while actively using social media (e.g., research purposes or writing a post) |

| | | |
|---|---|---|
| | | 7) Sitting or lying while talking to other people (on the phone or in person)<br>8) Not sitting |
| Item 1.3 (Follow-up "*Transport*") | "*What were you doing right before you started answering this survey?*" | 1) Sitting as a passenger while commuting<br>2) Sitting and driving a motor vehicle<br>3) Sitting a reading while commuting<br>4) Sitting a using a computer/phone for work/study purposes while commuting<br>5) Sitting and using social media or playing video games while commuting<br>6) Not sitting |
| Sitting Time | | |
| Item 1 | "*How many minutes were you sitting while studying/working yesterday? (include the time at University, during lectures, tutorials, meetings, group discussions, self-study, study from home, etc.)"* | Numerical value |
| Item 2 | "*How many minutes were you sitting or lying down while watching TV or playing video games yesterday? (e.g., watching TV in bed, playing computer games or playstation, playing games on your Iphone/Ipad/tablet, using the internet for activities that were not for studying or working purposes, like Facebook, Twitter, Skype, YouTube, online shopping, etc.)"* | Numerical value |
| Item 3 | "*Thinking again of yesterday, how many minutes were you sitting or laying down while reading during your leisure time? (include reading in bed but do not include time spent reading for paid work or for study)*" | Numerical value |
| Item 4 | "*How many minutes did you spend yesterday sitting down for eating and drinking?* | Numerical value |

| | | |
|---|---|---|
| | *(include meals and snack breaks)*" | |
| Item 5 | "*Please estimate the total time in minutes of yesterday that you spent sitting down to socialize with friends or family, regardless of location? (e.g., at University, at home, or in a public place. Include time on the telephone)"* | Numerical value |
| Item 6 | "*We are interested in any other sitting or lying down that may have done that you have not already told us. (e.g., hobbies such as doing arts and crafts, playing board games, listening to music, or for religious purposes. Again, thinking of yesterday, please estimate the total time you spent sitting or lying down NOT including time that you have told us about in the previous answers)* | Numerical value |