Exploring the Relationship Between Sedentary Behaviour and Meaning in Life in Young Adults: A Daily Diary Study With Continuous Physiological Data

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Abstract

Background: Previous research indicates increasing trends in sedentary behaviour (SB) and low psychological well-being among young adults. In the transformative stage of young adulthood, many are forming their identities and searching for Meaning in Life (MiL). The lack of MiL was found to be related to poorer mental health across populations and lower activity levels across older cohorts.

Aim of this study: As this connection is less researched in younger populations, the current study investigated the relationship between sedentary behaviour and Meaning in Life in their daily life.

Methods: Data was collected using daily diaries combined with non-invasive continuous physiological measures across 34 participants for eight days. SB was measured objectively through a tri-axial accelerometer from the EmbracePlus. Subjective self-reported MiL was assessed via daily diaries. The data of both were visualised and analysed with multilevel modelling.

Results: Visualisations showed that MiL stayed relatively stable across participants and for sedentary behaviour little variation in individuals daily sleep-wake cycles was evident. The mean adherence rate was above 90%. Multilevel modelling indicated no significant association between SB and MiL in young adults.

Conclusion: Given the lack of a significant relationship, reaching consensus on definitions and applicable methodology for MiL and sedentary behaviour individually is needed before further exploring their relationship. Future research with multiple assessment times and more context-inquiring questions could deepen understanding for each and influential factors. Due to high adherence, the methodology from this study shows promise in their applicability in young adults. Ultimately, this could deepen the understanding of both psychological and physical well-being in young adults.

Keywords: *Sedentary Behaviour, Meaning in Life, Objective physiological measures, Tri-axial Accelerometer, Daily Diary Design, Young Adults, Multilevel Modelling*

Contents

Introduction

Physical activity is widely recognised as playing an important role in increasing health and well-being, yet 28% of the global population fail to reach recommended activity levels (Guthold et al., 2018; WHO, 2022). This issue is particularly prevalent among younger cohorts, as studies indicate that 80% of adolescents do not achieve their recommended weekly physical activity and young adults are increasingly sedentary for seven to nine hours a day (Castro et al., 2020; Unick et al., 2017; WHO, 2022). The transitional stage from adolescence to adulthood is often characterised by an increase in sedentary behaviour (Aira et al., 2021; Corder et al., 2017). Individuals are starting college, moving away, and establishing careers, disrupting previous routines and separating them from environments and communities in which they were previously active (Aira et al., 2021; Corder et al., 2017; Higley, 2019). In this context, young adults are faced with re-establishing themselves and their habits, all while managing the new expectations and responsibilities of young adulthood.

Amidst these changes during young adulthood, mental health issues are prevalent. Silva et al. (2020) found that 25% of adolescents struggle with mental health disorders. Moreover, among university students, Ruiz-Hernández et al. (2022) saw a high prevalence of depression (33%) and anxiety (45%). As young adults are developing their identity, the search for Meaning in Life (MiL) gains central importance (Steger, 2009). In the study from Weissbourd et al. (2021) half of their young adult sample reported low MiL, which was significantly associated with reported mental health symptoms. Across research, MiL has been consistently associated with psychological well-being and mental health symptoms (Hadden & Smith, 2019; Haugan & Dezutter, 2021). Apart from its association with mental well-being, MiL has been identified as a significant factor influencing health behaviours and activity levels (Czekierda et al., 2017; Haugan & Dezutter, 2021). In the studies from Ju (2017), Lampinen (2021) and Sutin et al. (2021) significant associations between MiL and sedentary behaviour could be found in older cohorts. As these associations have not been explored extensively in young adults, exploring them in this population might be worthwhile in light of the inactivity levels in young adults as well as their quest for MiL. The impact of sedentary behaviour and the importance of mental health and Meaning in Life in young adulthood as well as their relationship will be discussed in the following paragraphs.

The Impact of sedentary behaviour

Across diverse populations, higher levels of SB of more than six hours per day have been related to higher risk for chronic and cardiovascular diseases, lower cognitive function and lower self-rated quality of life (Moulin et al., 2020; Patterson et al., 2018; Saunders et al., 2020). For sitting ten hours a day, the meta-analysis by Chau et al. (2013) found a 34% increase in mortality risk across diverse populations. As for time young people spend sedentary, the systematic review by Moulin et al. (2020) found that in university students sedentary time ranged from ten to eleven hours daily. For young adults specifically, sedentary behaviour has been associated with a decrease in physical fitness, higher obesity levels and higher risk of chronic diseases (Huang et al., 2022; Nelson et al., 2008; Salmon et al., 2011). Studies found that the negative effects of a highly sedentary lifestyle persist despite high engagement in physical activities (Dempsey et al., 2020; Ekelund et al., 2016). Only when engaging in extremely high levels of PA (>60 min per day), which is three time higher than the minimal recommended levels, the negative effects of SB could be offset (Dempsey et al., 2020; Ekelund et al., 2016).

The high sedentary activities in young adults are of a particular concern, as health behaviours formed and exhibited in the formative stage of young adulthood have been found to be predictive of health behaviours later in life (Nelson et al., 2008). In young adults the most common sedentary behaviour are screen-focused, which include computer usage and TV viewing and phone usage (Carballo- Fazanes et al., 2020; Hoare et al., 2016; Peterson et al., 2018). Many of them report the lack of time and place to exercise as well as a lack of motivation as reasons for physical inactivity (Martins et al., 2020; Carballo- Fazanes et al., 2020). In the case of high sedentary time psychological well-being was impacted as psychological distress was higher and mood and sleep levels were lower (Uddin et al., 2020; Ellingson et al., 2018). Given the impact sedentary behaviour has on various aspects psychological well-being, it becomes important to discuss a component specifically relevant in the transformational life stage of young adults, namely Meaning in Life.

Meaning in Life defined and as part of mental health

Meaning in life (MiL) is generally understood as a multi-faceted sub-component of psychological well-being, although consensus on the definition is lacking (George & Park, 2016;

Hadden & Smith, 2019; Heintzelman & Mohideen, 2022). This study relied on the commonly used definition of MiL from George and Park (2016), who define it as the "extent to which one's life experiences are making sense, are being directed and motivated by valued goals and are mattering in the world" (p.7). Furthermore the difference in assessing MiL as a trait or state level has been a topic of much discussion. Since the emergence of the discussion of meaning in life by Frankl (1963), it has been considered that MiL is not merely a trait but a state that can fluctuate (George & Park, 2016; Heintzelman & Mohideen, 2022). Research indicates that MiL fluctuates from day-to-day as it responds to changes in people's everyday lives and the given significance of sources of meaning (George & Park, 2016; Steger et al., 2006). Currently, the most used questionnaire for assessing MiL is the Meaning in Life questionnaire (MLQ) from Steger et al (2006), which aims to assess the presence and search for meaning. Another more recently developed questionnaire is the Three-Dimensional Meaning in Life Scale (3-DM) from Martela and Steger (2023). Both of these questionnaires showed high validity in measuring the construct of MiL (Martela and Steger, 2023; Naghiyaee et al., 2020)

In people's everyday lives MiL has been found to play a protective role in regard to mental health disorders, as Martela and Steger (2022) suggests a positive relation to psychological functioning. In particular, low levels of MiL have been shown to negatively impact mental health across all life stages and are highly correlated with reported psychological symptoms (Steger et al., 2009; Weissbourd et al., 2023). The study by Weissbourd et al. (2023) found that individuals expressing hopelessness about their future were generally more likely to report a lack of MiL. If high MiL was reported studies found it to be associated with increased positive affect, life satisfaction and vitality (Czekierda et al., 2017; Haugan & Dezutter, 2021; Hadden & Smith, 2019). Moreover, MiL has also been associated with several health indices and health behaviours, which is discussed below.

Meaning in life and its relationship with sedentary behaviour

Furthermore, MiL's influence also goes beyond mental health, as it was found to be significantly associated with increased physical health, engagement in health behaviours and activity levels (Brassai et al., 2015; Czekierda et al., 2017; Hooker et al., 2018). Sutin et al (2021) found that higher MiL was related to increased physical activity across diverse samples.

Studies using objective activity measures in exploring the relationship of activity with MiL, found MiL to be related with higher activity counts, more activity per day and less daily sedentary behaviour (Ju, 2017; Lampinen et al., 2006; Sutin et al., 2023). Although these studies found significant results, they focused primarily on the elderly population. The lack of exploring sedentary behaviour and well-being constructs such as MiL in younger samples, while using objective measures for activity levels have been pointed out repeatedly (Böckerman et al., 2017; Czekierda et al., 2017).

Nonetheless, there have been a few significant findings on the relationship between activity patterns, including sedentary behaviour, and MiL or related constructs across more diverse and younger samples. Studies that focused on younger cohorts, such as Brassai et al. (2015), found MiL to be associated with lower health-risking behaviours and in turn with an increase in health-protective behaviours in adolescents. In a study of well-being in students during the COVID-19 pandemic, Zhou and Hou (2022) found that MiL had a mediating effect in increasing activity and flourishing. Overall, sedentary behaviour was higher in young adults experiencing frequent stress (Uddin et al., 2021). Additionally, Maher et al (2014) saw that sedentary behaviour was negatively associated with satisfaction with life in college students, regardless of whether the activity patterns were self-reported or objectively measured.

Assessment of Sedentary behaviour

Previous research relating PA and SB mostly often assessed it through subjective self-report questionnaires (Lopez et al., 2023). Most studies employ subjective measures of SB, through self-rated questionnaires where participants are often asked to indicate duration, frequency, and type of SB they engaged in (Dempsey et al., 2020; Unick et al., 2017). Currently many studies point out the high SB across various populations, a discrepancy between self-reported and objectively measured SB is noticeable (Bauman et al., 2017; Unick et al., 2017). Although subjective questionnaires are easy to implement across larger samples and longer timeframes, limitations occur in accurately capturing activity patterns (Barisic et al., 2011; Unick et al., 2017). The questionnaires are subject to social desirability and recall bias, over or under-estimation of SB (Bauman et al., 2017; Moulin et al., 2020; Unick et al., 2017). In line with this,

Böckerman et al. (2017) stress that subjective measurements of activity are limited in the extent to which relationships and mechanisms with other variables could be explained.

Assessment in the context of everyday life

To gain a comprehensive picture of individuals' overall well-being, researchers are advocating for the contextualising of health and well-being into the experience of people's everyday life (Abaoğlu & Dogu, 2022; Haugan & Dezutter, 2021). Continuous objective physiological data gathered through accelerometers offer one possibility of how this could be done.

Due to the limitations of subjective measures and technological advances, objective measurement devices for SB are gaining popularity. Particularly tri-axial accelerometers, worn on the waist or wrist, show high accuracy, high compliance rates, low discomfort and low participant burden (Bonomi et al., 2009; Lopez et al., 2023). As these objective continuous physiological measures offer several benefits in assessing SB, it could further a deeper insight of SB in the context of everyday life and the fluctuations across days and individuals.

As suggested by Heintzelman and Mohideen (2022) as well as Hadden and Smith (2019), using measures that capture these fluctuations would provide insights into the subjective experience of psychological well-being including MiL and related behavioural patterns.

As research calls for contextualising this construct into the context of everyday life, the method of daily diaries shows promise. This approach is a part of the Experience Sampling method (ESM), which generally consists of gathering systematic self-reports at random times during a specified time frame (Larson & Csikszentmihalyi, 1983). Daily diary studies involve assessing participants' experiences and behaviours at a certain time or end of the day in natural settings (Lischetzke & Könen, 2021). Through this ecological validity of the findings can be increased while simultaneously investigating constructs close to real-time. This can provide detailed insights into intra-individual processes and changes between the assessment times (Ivarsson et al., 2020; Lischetzke & Könen, 2021). This method offers advantages such as capturing dynamic changes and reducing recall bias, although it also has limitations, including participant burden and potential biases in self-reporting as individuals are often asked to summarise some timeframe of experience (Lischetzke & Könen, 2021).

Combining the objective continuous physiological measures with daily diary self-report measures, as demonstrated by the study of Baglioni et al. (2023) in which they investigates sleep physiologically and subjectively while also relying on self-reported emotions. Another example is provided by Reichert et al. (2016) who used the experience sampling approach to assess mood while objectively measuring activity levels of participants using an accelerometer. The findings of these studies indicate that the methodology aided significant and novel contributions to the understanding of the circumstances and mechanism in the investigated relationships. This combined approach could offer a robust framework for examining if or how MiL and SB interact in the context of everyday life in young adults.

Aim of the current study

This study seeks to investigate the relationships between sedentary behaviour, and self-reported Meaning in Life in the daily life context of young adults. This will be done through addressing the research question of: "How is sedentary behaviour associated with changes in meaning in life in the everyday context of young adults?"

In light of this research question the null hypothesis can be formulated as follows: There are no significant associations between sedentary behaviour and changes in Meaning in Life in the context of young adults. Through exploring if or how sedentary behaviour affects meaning in life in the context of daily life, this study aims to contribute to a deeper understanding of their association in the context of everyday life by combining daily diaries with physiological markers measured non-invasively with smartwatches.

Methods

Design

This intensive longitudinal study combining daily diary and physical biomarkers constituted a component of a broader research project conducted by three researchers in the context of their bachelor theses. The project aimed to investigate the associations between psychological constructs and physiological parameters in young adults aged 18-30 in their daily life across eight days. For this, the overall research project employed a combination of the daily

diary method and continuous measurement of objective physiological data collected via medical-grade wearables. The purpose of this specific study was to investigate the relationship between sedentary behaviour and MiL in everyday life in young adults through measuring the ratio of engagement in sedentary behaviour, while inquiring about MiL in the evening. The study was approved on February 23, 2024, by the Ethics Committee of the Faculty of Behavioural, Management and Social Sciences of the University of Twente (Case number: 240133). To ensure a high degree of transparency and replicability, this thesis was written in accordance with the STROBE guidelines (Cuschieri, 2019).

Setting

Data collection began on March 18, 2024, and ended on May 13, 2024. Prospective participants from each of the three researchers' social circles were contacted. Additionally, the project was registered on the University recruitment system for participants (SONA). If individuals showed interest or signed up through SONA, met the inclusion criteria and where available for two meetings a week apart from each other, they were sent the participant manual (Appendix A). When setting up for data collection, participants had an intake meeting with the researcher. There they were given written and verbal instructions on participation and received the smartwatch and could ask questions about the study's procedure. They were then instructed on how to download the mobile application m-Path, which would allow the researchers to send questionnaires to the participants during the evening. The m-Path application and use are described in detail in the Data source section. Through m-Path they were again informed about the study design, procedure and methods and were asked to give their consent for participating in the study in the platform (Appendix B). Then, participants were sent a one-time landing survey through m-Path to gather demographic information (Appendix C).

After this they were asked to download the "Care lab" mobile application, which registers participants' information from the Embrace Plus. The information measured by the Embrace Plus are described in detail in the Data sources section. With the help of the researcher and instructions in the Care lab application they were instructed on how to put on the watch. The application would also alert them of occurring problems (i.e. lost connection, watch worn incorrectly) throughout the data collection period. Most importantly, as the Embrace Plus was

connected to the Empatica cloud through the Care lab application, real-time synchronisation of data could be ensured.

During the study participants wore the Embrace Plus, which passively and continuously sensed biometric data. The researchers used the Care application for real-time insight throughout and for accessing the data files at the end of the data collection period.

The m-Path daily diary questionnaires were sent to the participants between 6.00 PM and 9:00 PM for eight days. They were able to answer the questionnaire till 12PM and were reminded to answer through the app itself. Since the researchers had insights into completion of the questionnaire and adherence to wearing the watch, participants with low rates were reminded to answer the questionnaire on time. During the course of data collection, the researchers were available to address questions participants had. After the data collection, participants met with the researchers to return the equipment and synchronise the data collected by the Embrace Plus watches.

Participants

Participants were recruited via convenience sampling using the researchers' social networks and the university recruitment system (SONA). Participants were selected through assessing availability for the data collection time frame and if they met the inclusion criteria. Inclusion criteria were to be between the ages of 18-30 and fluent in English and as having access to a smartphone. Each participant gave their consent to participate in the study beforehand.

Data sources and Variables

In this study, the exposure variable of sedentary behaviour was the sedentary activity ratio aggregated in hourly measurements, monitored through the wrist-worn medical-grade wearable Embrace Plus. The outcome variables focused on the measure of Meaning in Life, which were indicated per day. The MiL construct was measured through items in a questionnaire answered through the mobile application m-Path, which are described in detail below. For the analysis the average of the selected MiL items was calculated and used as dependent variable

A daily diary design was chosen since the aim of the study was to gain insights into psychological constructs in the context of daily life while keeping participant burden minimal. This design was used for inquiring about MiL and the other psychological constructs selected by the other project members. This method was deemed most suitable, since it could provide an insight into people's lives, based on regular data collection provided by participants over a number of days (Nezlek, 2020). This approach proves especially useful when studying "naturally occurring phenomena" (Nezlek, 2020, p.2).

M-Path

In line with the daily diary design, the m-Path application was chosen as most suitable since it allowed for convenience and flexibility in administering the questionnaires. This application was developed by KU Leuven and is designed for both practitioners and researchers to assess clients in real-time and across several stages of research and interventions (M-Path, 2024). Overall the m-Path application is a free and flexibly tailored application that allowed for a real-time assessment and use as a feedback tool (Mestdagh et al., 2023). Through the application a daily questionnaire could be sent at a fixed timing schedule with one notification per day in the evening (Connor & Lehman, 2012). The questionnaire could be answered regardless of participants whereabouts, to gain insights directly from the context of their daily life. During data collection, participants were notified through the app when they were sent the daily questionnaire. If their adherence rate was low, they were reminded personally by the researchers.

Meaning in life questionnaire. As this study is part of a research project the questionnaire had a total of 18 items, including five items related to MiL (Table 1).

Table 1

MiL Items with the measured components, formulation and scale

Item	Component of MiL	Formulation in accordance with DD design	Scale
MIL1	Presence	Today I understood my life's meaning	1-7
MIL2	Searching	Today I was searching for meaning in life	1-7

MIL 3	Significance	Today my life was full of value	1-7
MIL 4	Purpose	Today I was highly committed to certain goals in my life	1-7
MIL 5	Coherence	Today I could comprehend what my life is all about	1-7

The other 13 items were related to other wellbeing constructs but were not included in this study (Appendix D). The MiL questions consisted of five statements for which the participants had to indicate on a 7-point Likert scale (Not at all true - Absolutely true) for how much they agreed with the statement. The original formulations, their reformulation and the questionnaire the items were selected from are presented in Appendix E. The first two questions were selected from the Meaning in Life Questionnaire (MLQ) (Steger et al., 2006) and the other three from Martela and Stegers (2022) three-dimensional meaning in life scale (3DM). To include different facets of MiL, items of different sub-constructs of MiL (presence, searching, comprehension, significance and purpose) with the highest factor loadings were selected from the two questionnaires (Martela & Steger, 2022; Nezlek, 2020; Steger, 2006).

All items were formulated in English in the pre-existing questionnaires and were adapted through reformulating them from their original present tense into the past tense (Appendix E). Additionally, they were reformulated to include “today”. This was done due to the nature of this study, asking them to reflect about their day in the evening. These reformulations were applied to keep the participants focused on the timeframe and constructs this study sought to measure (Nezlek, 2020). The amount of questions was limited, so participants would be able to complete the questionnaire in less than five minutes to keep the burden as low as possible and increase completion rates as recommended by Nezlek (2020) and Nulty (2008).

Embrace Plus

For this study the EmbracePlus smartwatch, lend through the BMS lab at the University of Twente, was used to objectively measure a range of physiological parameters, including the sedentary activity ratio needed for this study (THE BMS LAB, 2024).

The EmbracePlus smartwatch was selected for this study as such wearables have the advantage of being easy to use and non-invasive through their wear-and-forget functionality (Erdem et al., 2024). The EmbracePlus is a medical-grade wearable typically worn on the wrist, with multiple sensors able to measure a wide range of physiological biometrics, such as motion-based activities, electrodermal activity, respiratory rate and heart rate variability (Empatica, 2024; Perego, 2019). As of now the EmbracePlus has been used for studies on activity, epilepsy, physical fatigue and stress (Shishavan et al., 2023; Albarrran Morillo & Demichela, 2023; Onorati et al., 2021; Weale et al., 2023).

Through its portability, low participant-burden and continuous-passive measurement of biometrics, this device is suitable for studies with a longer time frame (Perego, 2019; Xu et al., 2018). These advantages allow for easy use and high adherence in the context of everyday life (Albarrran Morillo & Demichela, 2023; Xu et al., 2018). Overall, the EmbracePlus has been pointed out to be a well-performing and easy to use wearable for continuous non-invasive health monitoring (Shishavan et al., 2023; Albarrran Morillo & Demichela, 2023; Perego, 2019). Regarding the validity and reliability of specific measures only some were explored. Previous studies found the measures of oxygen saturation heart rate and heart rate variability to indicate a high degree of validity (Gerboni et al., 2023; Schuurmans et al., 2020). Some measures such as electrodermal activity had diverging outcomes, as Ronca et al. (2023) found it to be reliable, whereas Borrego et al. (2019) and Milstein and Gordon (2020) indicated low reliability. In the specific case of the activity measures from the devices accelerometer no specific studies exploring the validity and reliability were found as of now.

Sedentary ratio. Objective physiological data of participants activity patterns was continuously gathered through the Embrace Plus smartwatch and its integrated gyroscope and tri-axial accelerometer, measuring x-,y- and z-axis of movement by the watch worn on the wrist (Empatica, 2024). Embrace Plus provides several classifications for activity (sedentary, light, moderate and vigorous), however the cut-off points and calculations behind these classifications were not disclosed in the raw data and manual. According to research, Empatica and most accelerometers use device-specific algorithms to calculate and classify these activity levels (Jaeschke et al., 2020; Perego, 2019).

The Embrace data classified the measured activity into sedentary, light, moderate and vigorous activity for each participant, based on the measured in each minute. To be able to analyse sedentary behaviour, the activity classifications were divided into non sedentary activity and sedentary activity, where light, moderate and vigorous activity were coded as non-sedentary and the remaining activity as sedentary. Then the sedentary ratio was quantified and aggregated into hourly ratios (i.e. the original 1 minute sample rates were averaged for 1 hour as a preprocessing step). This ratio indicated per participant and per hour could then be used to compare relative differences between individuals.

Sample Description

Collected socio-demographic variables were age, gender, nationality and occupation status (student/student and working/working). These variables were gathered at the start of the data collection for each participant through the m-Path landing survey. These variables were only used to describe the sample, since no covariate adjustment was performed in the multilevel model.

Bias

To address potential sources of bias, participants received detailed written instructions (Appendix X) and were again fully informed verbally about the procedure during their meeting with the researchers. With the hopes of increasing reliability and validity it was stressed that data will be anonymised. Since over- and under-estimation of inquired constructs are often an issue in questionnaires, participants were asked to answer items as truthfully as possible with the goal of increasing reliability. Additionally, the value and contribution of the participants through wearing the watch were stressed, which has been shown to increase adherence and wearing time in similar studies (Xu et al., 2018). During the study participants received reminders from the researchers, since maintaining contact with participants has been indicated to have a positive effect on adherence (Robiner, 2005; Xu et al., 2018). Furthermore, overall responsiveness of the researchers was prioritised in this study, as Xu et al. (2018) found it to have a positive effect on response and adherence rates.

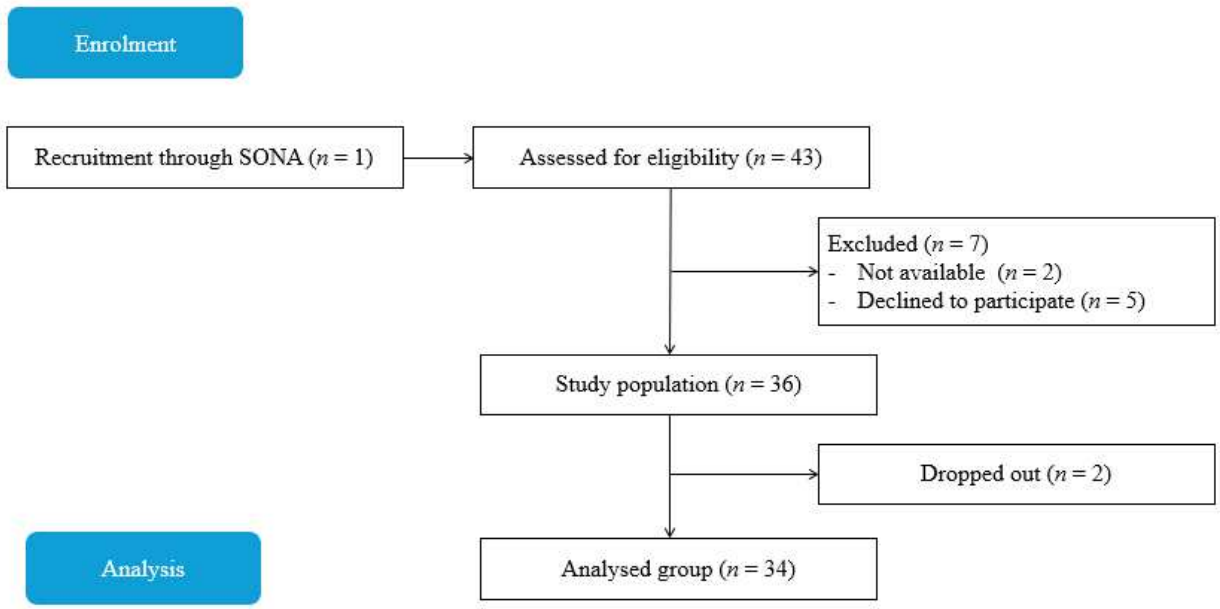
In order to further stimulate adherence there was a possibility of winning a 50-euro gift when adherence for both wearing the watch and filling in the questionnaire was ≥ 80. This criterion was communicated to the participants at the start of the study. When recruited through SONA, participants received 2.5 SONA points for their participation. Generally, receiving rewards as a means of positive reinforcement for participation as well as receiving rewards for high adherence has been shown to effectively increase adherence (Robiner, 2005).

Study size

As seen in Figure 1, a total of 43 people were eligible, out of which one was recruited through SONA. Out of the 43 five were not interested and two were not available during the suggested time frame. As 35 people were interested, and one person was recruited through SONA, the study population consisted of 36 participants. However, two people dropped out during the course of the study, so the final analysed sample consisted of 34 participants. Participants were excluded if they completed ≤ 50% of the daily questionnaires and wore the wearable for ≤ 50% of the time across the study.

Figure 1

Flowchart of recruitment, included and excluded participants and final sample



Data analysis

Pre-processing, missing data and exclusion

Through the Care application raw data files from the EmbracePlus measures were downloaded via an access key created in the Care website. The m-Path data was accessed through the researchers m-Path website and exported as excel files and anonymised. Then both the m-path and embrace data were uploaded to the University OneDrive server to which only the three researchers for the project and the project supervisor had access to. The data was organised into separate participant folders. Data was last uploaded on the 20th of May 2024 at 23:11 CET.

To be able to conduct the necessary statistical analyses RStudio (4.4.0) was used. The used packages can be found in the Appendix F. To prepare the data for statistical analysis the data was pre-processed through organising the data by participant and date. The activity intensity data was extracted, and the timestamps of the collected measure were converted to ensure date-time values were stored in a consistent format, allowing for easier comparisons and sorting (Jones et al., 2021). Due to the original one-minute sampling rate of the Embrace Plus, the activity metrics were aggregated into hourly measures to reduce the data size as well as enhance comparability and interpretability during analysis. The hourly measures were calculated by summarising the data to count the occurrences of sedentary and non-sedentary periods and then calculating the ratio of sedentary periods to the total periods. Furthermore, the Embrace and m-Path data were merged into one data frame. The final data set contained the hourly physiological measures of each day and the questionnaire scores from the answered days for each participant.

The missing values from the Embrace Plus data at the start and end of each participant's trial were excluded in cases all rows of the physiological measures were zero or NaN., This was due to the fact that the devices were turned on and off at different times during the day. Missing values were generated between midnight of the same day until activation or deactivation which is why the output files included observations for each minute from the day in which the device was turned on or off. Since data on the MiL items was only assessed in the evening, these indicated levels were filled for the respective days. For this the less observation carried forward approach (LOCF) was used (Overall et al., 2009). The rows of the unanswered days were left empty. After filling the items scores for the respective days, the separate MiL items were combined and the

mean of this overall score was calculated for each day. The adherence rate for wearing the watch and answering the questionnaire were calculated for each participant and the total sample. The overall adherence rate of both measures was also calculated.

Multilevel modelling (MLM)

Multilevel mixed models were used as they can work with the nested structure of the data and the missing values (Nezlek, 2020). The package lme4 (version 1.1-35.4; Bates et al., 2015) was used to run mixed models. To visualise the plots for each measure ggplot2 (version 3.5.1; Wickham, 2016) was used. The steps from the tutorial from Kleiman (2017) were used as guidance in analysing the multilevel data and writing the code and are described below.

The first step for analysing data with two levels was testing the unconditional model to test if multilevel modelling is the fitting approach. For this, the dependent variable and Participant ID were entered into the model, without a predictor variable. Based on the output, MLM was appropriate for all models if their p-value would be < .05, which shows that there is significant between-participant variation. Since MLM was determined to be appropriate, the predictor (sedentary ratio) was added in the next step. The model with sedentary ratio as predictor and the MiL measures as outcomes had random intercepts for each participant and with fixed slopes.

Results

Descriptive statistics

In the final sample, there were 34 participants. The participants' mean age was 21.45 (*sd =2.05*). Regarding gender, half identified as female and the other half as male. As for nationality, the majority (94.1%) of participants were German. Additionally, half of the participants indicated that they were full-time students, 34.5% were students and working and the remaining people indicated to be working (5%).

Table 2

Sociodemographic characteristics of Participants

Baseline characteristic	Participants

	n	%
Gender		
Female	17	50.0
Male	17	50.0
Age		
Mean (*SD*)	21.45 (*2.05*)	
Occupation		
Student	17	50.0
Student & Working	12	35.3
Working	5	14.7
Nationality		
German	32	94.1
Dutch	1	2.9
Vietnamese	1	2.9

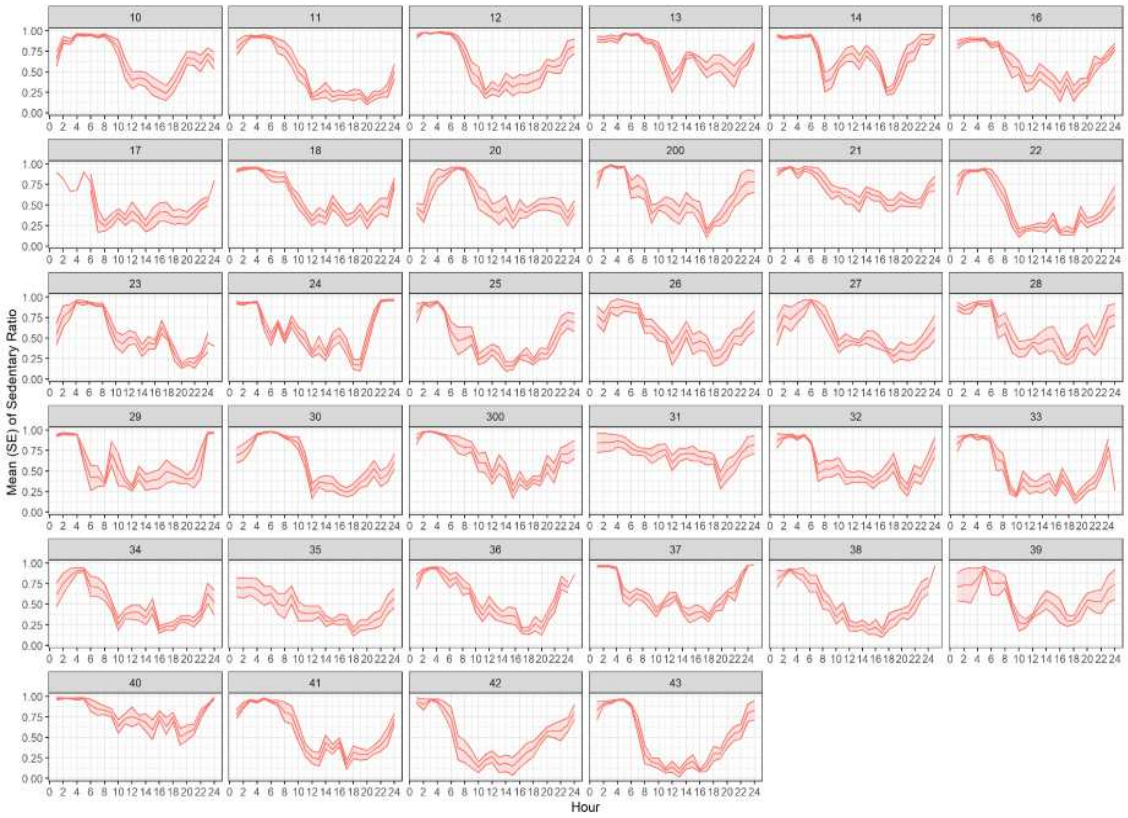
The adherence rates across participants can be seen in Appendix G. The adherence rate for wearing the watch was 87.66%. For the questionnaire the rate was slightly higher with 93.06% adherence across the participants during the eight days. The mean adherence rate across the sample for wearing the watch and answering the questionnaire was 90.47%.

Sedentary ratio

The fluctuations of sedentary ratio are visualised in Figure 2. The graphs were plotted for each participant, as indicated by the participant's pseudo anonymised ID on the top of each plot. The middle line represents the mean hourly sedentary ratio across. The two outer boundaries visualise the standard error. The graphs for each participant depict the hourly mean of the sedentary ratio across the hours for all study days.

Figure 2

Time series plot of mean sedentary ratio across participants and hours with standard deviation



Note. The x-axis (Hour) indicates the hours of the days as it ranged from 0 to 24. The sedentary ratio represented on the y-axis ranges from 0.00-1.00, indicating the average hourly ratios of the original 1 minute sample rates. The solid red middle line represent the mean sedentary ration and the ribbon on either side indicate the standard error. The numbers on top of each graph indicate the pseudonymised ID of each participant.

The plotted curves reflect the daily cycles of activity and sleep, as the sedentary ratios are high at the start of the day and start to decrease over the course of it and then increase again at the end. This means that higher values indicate higher sedentary behaviour in each hour bin, and lower values indicate lower sedentary behaviour (i.e. more activity). These daily sleep-wake cycles can be seen in all participants although with different start and end points, indicating individual sleep-wake rhythm. Variation within participants was not very high, since similar patterns between days were evident, as the standard errors (i.e. the levels of dispersion around their mean levels) were not very high.

Meaning in life

Across the seven to eight days the overall MiL value fluctuations can be seen in Figure 3 across all 34 participants. The possible scores as shown on the x-axis range from 0-7, with 0

being the lowest and 7 the highest possible score. On the x-axis the day number is indicated, indicating the fluctuation levels of MiL across the study. The number on top of each graph corresponds to the participant ID, the middle red line represents the mean MiL score, and the two outer lines visualise the standard error.

Figure 3

Mean MiL scores across participants across eight days

Note. The x-axis indicates the days of participation for each participant and the y-axis represents the scale from the MiL items, which ranged from 1-7. The solid red line in the middle represents the mean MiL score and the ribbon in either side indicate the standard error. The numbers on top of each graph indicate the pseudonymised ID of each participant.

Although fluctuations within participants were visible and more participants had minimally lower MiL scores at the end of the study, for half of the participants MiL fluctuations

were minimal (below one point increase or decrease) which indicates that MiL stayed relatively stable. Four participants even indicated the same start and end score. Overall, the highest and lowest scores were rarely indicated. Out of the 34 participants, four participants indicated higher MiL scores in the end than at the start, with one participant (43) out of the 34 scoring MiL more than two points higher at the end of data collection than at the start. For the remaining three (30, 31, 37) the scores were about one point higher at the end than at the start. Five (10, 24, 300, 33, 35) of the participants scored lower on MiL at the end than at the start, although the decrease differed from the start value by one for three and above two for one and above three for one. Another pattern that was observed is that significant fluctuations in either direction often were followed by a fluctuation in the opposite direction.

Multilevel modelling

To explore the relationship between the MiL and sedentary behaviour multilevel modelling was used (Table 2). The model was fitted to predict the mean MiL score with sedentary ratio as a fixed effect and the participant as a random effect.

Table 2

Multilevel regression model results for sedentary behaviour and meaning in life

Predictors	*Estimates*	*std. Error*	*std. Beta*	*standardised std. Error*	*CI*	*standardised CI*	*p*
(Intercept)	3.60	0.16	-0.00	0.14	3.29 – 3.92	-0.28 – 0.27	**<0.001**
sedentary ratio	-0.01	0.03	-0.00	0.01	-0.07 – 0.05	-0.02 – 0.02	0.850
Observations	5231						
Marginal R^2 / Conditional R^2	0.000 / 0.648						

The model intercept was 3.60 (95% CI [3.29, 3.92], $p < .001$), indicating that the estimated MiL scores were 3.60 when the sedentary ratio was zero. The intercept was statistically significant as the p-value was below 0.001. Based on the model output, it can be said that the model had substantial explanatory power, as 65% of the variance in the MiL scores was

explained by the models' fixed and random factors (Conditional $R^2 = 0.65$). Sedentary ratio as a fixed effect did not explain the variance in the MiL scores as the variance explained by the sedentary ratio on its own was zero (Marginal $R^2 = 0.00$). The beta score of -0.01 (95% CI [-0.07, 0.05], $p = 0.850$) indicated that for each unit increase of sedentary ration the MiL score would decrease by 0.03. However, since the p-value is above 0.05, the effect was not statistically significant. Due to this, no evidence was provided, based on this model and data, that an association between sedentary ratio and MiL scores exists. Thus, the null hypothesis was accepted, indicating no relationship between the sedentary behaviour and Meaning in Life in this sample.

Discussion

This study investigated the association between Meaning in Life and sedentary behaviour in young adults in the context of their daily life using unobtrusive continuous physiological measures and a daily diary questionnaire. The results of this study indicated no significant relationship between sedentary behaviour and Meaning in Life in young adults.

Since this study sought to address several research gaps, the first one through investigating sedentary behaviour and Meaning in Life in a younger population and secondly through using both continuous objective activity data and subjective daily diaries. As of now there are no studies investigating the relationship between sedentary behaviour and MiL while applying the methodology of daily diaries and objectively physiological activity measures in young adults.

Contrary to this study, some studies reported a significant relationship between MiL and sedentary behaviour, such as the study by Sutin et al. (2021), Hooker and Masters (2018) and Abaoğlu and Dogu (2022). Sutin et al. (2021) found higher MiL to be associated with less continuous sedentary behaviour using an accelerometer and assessing MiL through one item of the Meaning in Life questionnaire. Hooker and Masters (2018) reported that increased MiL was associated with more activity in previously inactive individual. Lastly, Zhou and Hou (2022) found that when individuals were less active, their perceived MiL was negatively affected. Although it has to be noted that these studies were not primarily focusing on sedentary behaviour but physical activity. Furthermore, only Zhou and Hou (2022) had a younger sample compared to the others and they as well as Hooker and Masters (2018) assessed activity subjectively. This

pattern was observed in the majority of studies, as most focused on physical activity and had only a few had young samples.

Although some studies used objective measures to assess activity, most focused on physical activity rather than sedentary behaviour. Both Sutin et al. (2023) and Hooker and Masters (2016) used accelerometers to objectively assess activity but focused on Purpose in Life and not MiL. They found Purpose in Life to be positively associated with physical activity and less continuous time spend inactive. There were several studies that used the Purpose in Life scale and used it interchangeably with Meaning in Life while investigating the relationship between physical activity, like the study of Abaoğlu and Dogu (2022). In this study they found only a weak association between Purpose in Life and activity levels, but activity levels were assessed subjectively. Generally, Purpose in Life was a more widely explored construct in the relation to activity measures.

Studies that did investigate MiL and activity levels often relied on subjective measures. Ju (2017) and Brassai et al. (2015) both used subjective activity measures, as a people were asked about their physical activity in a questionnaire. In the older sample in the study by Ju (2017), physical activity was positively related to both MiL and subjective vitality. Brassai et al. (2015) found MiL to be predictive of health behaviours such as physical activity in adolescents. As they investigates MiL and physical activity in adolescents, they were one of the few studies using a younger sample. Both used the Meaning in Life questionnaire to assess MiL at the start of the study.

The Meaning in Life questionnaire from Steger et al. (2006) was used the most in studies investigating MiL and activity (Zhou & Hou, 2022; Sutin et al., 2021, Ju et al., 2017; Brassai et al., 2015). In this they differed from this present study used both items from the Meaning in Life questionnaire and Three-Dimensional Meaning in Life questionnaire. The Three-Dimensional Meaning in Life questionnaire was not mentioned by the discussed studies. Another difference that can be noted is that these studies only assessed MiL at the start and end of the study or the admittances where not explicitly named. In this present study MiL was assessed using daily diary at the end of each day.

Other constructs related to psychological well-being, such as Satisfaction with Life, were also often explored in relation to activity measures in both younger and older samples. The results from Zayed et al. (2018) suggest that higher physical activity was associated with better

mental well-being and higher life satisfaction. The study by Uddin et al. (2020) was one of the few studies focusing on young adult and sedentary behaviour, although they investigates life satisfaction and not MiL. In their study they found that higher sedentary behaviour was linked higher distress in young adults.

The methodology Maher et al. (2014) aligned most with the one from this present study. They had a sample of college students in which they assessed physical activity and sedentary behaviour objectively and used daily diaries for assessing well-being constructs. However, Maher et al. (2014) did not focus on MiL as a well-being construct and instead assessed satisfaction with life through daily self-report questionnaires. Their findings suggest that less sedentary behaviour was associated with increased satisfaction in life in young adults. Other studies focusing on young adults often investigated other psychological constructs in relation to activity. The study by Ivarsson et al. (2020), assessed activity subjectively in university students, while inquiring about core affects at the start and end of the study. They found regular physical activity to be related to increased psychological well-being. The few studies focusing on younger populations of Brassai et al. (2015), Ivarsson et al. (2020), Maher et al. (2014), Uddin et al. (2019), Zhou and Hou (2022) suggest that psychological well-being constructs are positively associated with physical activity but due to the lack of research this cannot be said for sedentary behaviour.

Overall, the consensus of most of these studies was that higher engagement in sedentary behaviour is negatively associated with psychological well-being constructs and higher engagement in physical activity was positively associated with psychological well-being. Although the other investigated constructs of Purpose in Life and Satisfaction in Life are related to MiL and there is some overlap in the conception of the constructs and the wording of items, they are not the same and are based on different questionnaires. Additionally, the differences in measuring MiL only at the start and end of the study or through daily diaries make it difficult to compare the findings, as well as the fact that some studies used Purpose in Life interchangeably with MiL. Furthermore the baseline stability of MiL across this presents study's sample indicates that MiL was potentially measured at the trait-level and not the state-level, as it was only assessed once a day. Research shows that for MiL fluctuations within participants have been argued to occur due to certain live events or even seemingly mundane events (Chen et al., 2021;

Hadden & Smith, 2019; King & Hicks, 2020). This might suggest that other factors impacted MiL in days that showed fluctuations that were not accounted for.

Multiple studies pointed out that although sedentary behaviour and physical activity are related to MiL, other very significant sources of meaning are family, interpersonal relationships, occupation and friends (Grouden & Jose, 2014; King & Hicks, 2020; Silver et al., 2021). Especially for young adults, personal growth was indicated to be a source of meaning as well as friends, occupation, their education and their hobbies (Grouden & Jose, 2014; Silver et al., 2021). As leisure time activities as well as work can be sedentary but classified as mentally active, the impact of these activities might be significant to assess and to explore if they have an effect on the experience of MiL even though they are sedentary.

Interestingly, the systematic review by Ramalho et al. (2018) alludes to the different effects of sedentary behaviour affecting the association to well-being and meaning related constructs, depending on if the sedentary behaviour can be classified as active or passive. When individuals engaged in sedentary behaviour that could be categorised as mentally active (e.g reading), it had a positive association with mental health. Similarly, in an older cohort in a study by Ekelund et al. (2021), negative relations of sedentary behaviour and well-being measures were primarily indicated when sedentary behaviour was described as involuntary by participants. For elderly populations, Huang et al. (2020) found that mentally passive sedentary time has a negative effect on mental health indices, whereas mentally active sedentary time had the opposite effect. The distinction of mentally passive and active sedentary behaviour also played an important role in Werneck et al.'s (2021) study on adolescents. Their participants spend higher continuous bouts sedentary when these behaviours were mentally passive (e.g watching TV).

Strengths and Limitations

Strengths

As for the strengths of this study it can be noted that the use of objective physiological measures in daily life in young adults addressed an existing gap as most studies rely on self-report data and focus on older cohorts. Furthermore, the high adherence rate for wearing the watch as well as the high completion rate for answering the questionnaire indicated that the methodology could be applied well in the population of young adults. Additionally, gathering

data from 34 participants for eight days each across eight weeks despite limited time and resources of the three researchers was considered a success.

Limitations

However limitations in the measurements, methodology as well as sampling and data collection can be named. Firstly, although the sleep-wake rhythms across participants were visualised, this study did not differentiate between sedentary behaviours during sleep and wake states. Gibbs et al. (2015) point to this being an important distinction and that differentiating between sedentary activities of each state could increase reliability and validity of findings. Inquiring about the context of and classifying sedentary activities could increase the validity and contribute with novel findings which could ultimately aid research and development of interventions (Magnon et al., 2018).

Secondly, objective measurement devices such as tri-axial accelerometers are criticised for current technical limitations in accuracy for some activities (i.e measuring standing activity) (Bonomi et al., 2009; Lopez et al., 2023). The reliability is questioned as thresholds for classifications of intensity levels are often decided by researchers independently or computed by companies' device-specific algorithms (Perego, 2019; Tarp et al., 2018). Furthermore, this present study relied on pre-processed data by the Embrace Plus. Therefore future studies could consider working directly with the raw signal since continuous objective measures of give important insight into these behaviours in the context of people's daily lives. This aids quantification and understanding of the behaviour itself, as well as its effects on health outcomes (Gibbs et al., 2015; Bonomi et al., 2009; Sember et al., 2020).

Furthermore, the MiL construct was measured by only five items across eight days, which is a relatively low number and short time-frame. None of the items were validated for the use in the daily diary design of this study. Due to this the reliability of the findings might be undermined. Responses might also have been affected due to the questionnaire being in English which could have posed a challenge for non-native speakers, which were the majority in this sample. King and Hicks (2021) point out the challenges in measuring MiL, as individual conceptualisation of MiL makes this construct difficult to measure. Czekierda et al. (2017) stress that the different conceptualisation of meaning lead to different measures which they point out as the origin of discrepancies in associations between MiL and health measures. This is in line with general criticism of the study of MiL is the lack of consistent definitions across researchers and

people, as it is pointed out to be a subjective and abstract construct (George & Park, 2016; King & Hicks, 2021).

Implications and Suggestions for Future research

Future research should firstly aim to contribute to consensus on MiL and sedentary behaviour in both its conception and methodology. The observed lack of a significant relationship between sedentary behaviour and MiL in young adults could suggests that important distinctions are needed regarding the context and types of sedentary behaviour in order to explore if or how this would affect the association. Only when the consensus in the definition, classification and measures is increased for each construct individually, exploring the relationship between MiL and sedentary behaviour could be more worthwhile. Then possible moderators and confounders should be taken into account to explore the relationship between sedentary behaviour and MiL.

Since criticism on sedentary behaviour by Magnon et al. (2018) highlights the need for distinguishing postures, standing and sitting as well as sleep and wake states further improvements could be made to the current accelerometer algorithms. The review by Sui et al. (2021) highlights that the degree of association between sedentary behaviour and psychological well-being differed based on the way activity was assessed. Striving for consensus on the definition of sedentary behaviour and determining it is more accurately assessed subjectively or objectively needs to be prioritised.

As of now objective physiological activity measures show increased accuracy of activity patterns compared to subjective measures (Lopez et al.,2023). This could be increased even further through personal algorithms for activity assessment and classification of activities that could take individuals weight, gender and fitness level into account, increasing the preciseness of calculations (Coravos et al., 2019; Lopez et al., 2023). Additionally, the use of multiple accelerometers or considering different placements could improve accuracy, as Bonomi et al. (2009) found a higher accuracy for measuring PA for hip-worn accelerometers than for those worn on the wrist.

For MiL since it has been discussed as being influenced by many environmental factors and life events and therefore it has been theorised to fluctuated within-participants on a day to day basis. Future studies could employ ESM with multiple assessment times per day to gain

more context about the situation around MiL and its fluctuations within individuals (George & Park, 2016; Hadden & Smith, 2019; Heintzelman & Mohideen, 2022). This could also be done for sedentary behaviour, as participants could be asked about the context and type to be able to classify the activity into mentally active and passive and to gain deeper insights into potential influential factors (Ekelund et al., 2021; Ramalho et al. 2018; Werneck et al., 2021). By assessing sedentary both objectively and subjectively as well as assessing the context and type multiple times per day, clarity could be reaching in what sedentary behaviour is as well as influential factors.

All in all, a consistent definition of MiL as well as a consistent classification of sedentary behaviour should be prioritised to enhance the comparability of studies. Generally, future research should investigate each construct more extensively on its own to gain clarity on its characteristics and contextual factors, which could be achieved through using a similar methodology as presented in this current study.

Conclusion

This study aimed to combat an existing research gap as well as exploring the relationship using objective continuous physiological measures and daily diaries to assess sedentary behaviour and MiL in the daily life of young adults. Although no significant relationship between the explored variables was found, the high adherence rates and success in using the combined methodology, highlight the potential for using these methods for future research. In light of increasing sedentary behaviour and low MiL in young adults, these topics should be explored independently in the future and consensus on each is needed before exploring their potential relationship further. This could be done through future studies making use of this combined methodology with larger samples, across longer time frames, assessing context and other variables more specifically. With future research and findings, development of interventions for improving both physical and psychological well-being in this population could be advanced.

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AI statement

During the preparation of this work the author used ChatGPT in order to give suggestions and improvements for the code used in the data analysis and for suggestions for shortening texts or synonyms for words. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

Appendix A

Consent Form

Welcome! You are invited to participate in our bachelor thesis study exploring the use of physical biomarkers and their connection to variables of positive and negative affect, self-esteem and meaning in life
Before you decide whether to participate, it is important that you understand the purpose, procedures and potential risks.

Purpose: The purpose of this study is to investigate the meaning of physical biomarkers in everyday life. In particular, the variables of positive and negative affect, self-esteem and meaning in life will be assessed through daily questionnaires and correlated with the assessment of the biomarkers. The examination of these relationships allows for a deeper understanding of the role of physical biomarkers in everyday human experience and provides valuable insights into the dynamics between psychological states and biological markers.

Duration: The duration of this study is expected to last seven to eight days.

Procedure: If you agree to participate, you will be asked to wear the Embrace Plus watch, which will measure physiological and behavioural parameters. In detail the watch will measure: Blood Oxygen Saturation, Sleep detection, Electrodermal activity, Skin Conductance levels, Temperature, pulse rate, Respiratory rate, Pulse rate variability, Wearing detection, Energy expenditure as well as Actigraphy measures (6MWT, Advanced gait analysis, raw 3-axis accelerometer)

I have read and understood the study information dated [08/04/2024], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction (yes/no).

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason (yes/no).

I understand that taking part in the study involves wearing the Embrace Plus watch all day (except when being in the water) and filling in a questionnaire once a day (yes/no).

I understand that information I provide will be used for a bachelor thesis (yes/no).

I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the study team (yes/no).

The data will be anonymised. If future publications utilise this study's data only groups estimates (e.g., mean, median, standard deviations, max, min, etc) will be reported. By clicking this box, I give permission for the questionnaire data and biomarker data that I provide to be archived in the UT data storage so it can be used for future research and learning (yes/no).

I understand what taking part in this study will involve. I agree to take part in this study (yes/no).

Appendix B

Manual for Participants

Everything you need to take part in this research should be covered in this manual.
Take your time going over everything, and do not hesitate to get in touch with the researchers if you have any questions, are experiencing technical problems or if you want to withdraw from the study:

Sophie Spierenburg,
Carolina Annabell Klingebiel,
Leonie Döhrmann

What is the purpose of the study?

The purpose of this study is to investigate the meaning of physical biomarkers in everyday life. In particular, the variables of positive and negative affect, self-esteem and meaning in life will be assessed through daily questionnaires and correlated with the assessment of the biomarkers. The examination of these relationships allows for a deeper understanding of the role of digital biomarkers in everyday human experience and provides valuable insights into the dynamics between psychological states and biological markers.

What is to be expected during the research?

Every day for 8 days you will be asked to answer a questionnaire via the app ***m-Path*** on your mobile phone. The daily questionnaire will appear every evening at 18-21.00.
During these 8 days you will additionally be asked to wear the ***EmbracePlus*** watch **day and night**.
You will additionally be asked to download the ***EmpaticaCareLab app*** for the upload of your watch's data. Ensure that your phone always has an internet and Bluetooth connection and ensure the watch is connected, which can be checked through the EmpaticaCareLab app, this will ensure a continuous synchronisation of data.
When you are requested to set up an account using your email but prefer not to use your personal email, you have the option to utilize *Proton Email* service at no cost (link on last page). This allows you to quickly establish a secure, anonymous, encrypted email account.
If you adhere to the protocol (wearing the watch for > 80% of the time and completing > 80% of daily diaries) you will go to a pool (of all participants of this study) where a 50-euro Amazon gift card will be raffled.

How does *mPath* work?

MPath is a mobile application through which questions can be sent to you.

1. First you download the mPath app
2. You are then asked to provide a nickname (you do not have to provide your real name, to protect your privacy you can also provide numbers or an alias)
3. After accepting the terms, you can connect to our study through clicking on "Your practitioner" and then on the plus symbol, where you can then look for **@zcfp9** to add us as your practitioner.
4. Enable notifications for this app on your phone
5. For this study, you will be sent a consent form and a landing survey once at the start the study.

After these first steps you will receive a daily questionnaire between 18.00-21.00 (at the time you prefer in the landing survey) consisting of 18 items for 8 days. You can click on the notification or go to the app manually within this time frame. You will see “start the questionnaire” on the bottom of the page. We ask you to answer each question as truthfully as possible. Your answers are automatically and securely processed and stored in the researcher's dashboard.

How does the *EmpaticaCareLab app* work?
The EmpaticaCareLap app is part of the monitoring system of the EmbracePlus. Through this application you as a participant can check if the data is synchronising and if you are wearing the watch correctly. Please, activate the Bluetooth function of your device to connect the app to the EmbracePlus wearable. Additionally, your wearing time, pulse rate and skin temperature are displayed in the app.

The charge of the watch lasts approximately two days, so please recharge the wearable for about 1 ½ hours, when necessary, with the included charger.

Please do not wear the EmbracePlus during showers and when swimming. It is recommended against to use it in water (despite the IP67 certification).
If the EmbracePlus **gets damaged** at any point, please notify the researchers **immediately,** there will be **no repercussions** for you, but we are required to inform the lending institutions of its damage.

How does the *EmbracePlus* work?
The EmbracePlus is a smartwatch designed for continuous health monitoring.
Place the EmbracePlus wristband top-down on a surface. Wrap the band around the wrist while making sure that the button is on the outside of your wrist. For reference look at the picture below. The EmbracePlus should be worn behind the knuckle. Make sure it is fixed and can’t wriggle back and forth. Wear it on your non-dominant hand with a finger-width from your wrist bone. Check the underside if you want to make sure the wearable is recording, you should be able to see a green light.

How can I be sure the EmbracePlus is correctly recording?
Look out for the following signs

Place the EmbracePlus on your wrist

Wear it on your non-dominant hand for more accurate monitoring. Your EmbracePlus should be a finger's width from your wrist bone.

CARE LAB APP

Open the application and check that:

- ☑ The background is teal;
- ☑ The Status card reads 'Care is running smoothly';
- ☑ Wearing time is increasing;
- ☑ The Participant has the correct EmbracePlus. You can check this by looking at the serial number on the EmbracePlus, and comparing it to the serial number in the Settings menu of the Care Lab App

EMBRACEPLUS

Check the EmbracePlus and verify that:

- ☑ The display is light;
- ☑ The Empatica heart icon is visible;
- ☑ The sensor is on (there is a green light from the bottom of the device)

The Empatica heart icon tells you if the watch is connected to the app. If the watch is momentarily not connected to the app (no heart icon) the watch will upload the missing data when you are connected to the app again. Make sure your device with the Care Lab App has Bluetooth activated and is close to the EmbracePlus wearable.

What does the *EmbracePlus* measure?

In detail the watch will measure:

- Blood Oxygen Saturation (SpO2)
- Sleep Detection
- Electrodermal Activity (EDA)
- Skin Conductance Level (SCL)
- Temperature
- Pulse Rate
- Respiratory Rate
- Pulse Rate Variability
- Wearing Detection
- Actigraphy Measures:
  - 6MWT
  - Advanced Gait Analysis
  - Raw 3-axis Accelerometer Data
  - Wearing Detection
  - Activity Counts
  - Energy Expenditure
  - Body Position

Links:

For more information about the applications and EmbracePlus:

EmbracePlus and EmpaticaCareLab: https://www.empatica.com/en-gb/

MPath: https://m-path.io/landing/

Proton E-mail free account: Proton Mail: Registrierung

Appendix C

Landing survey

1. What is your gender Identity?
    a) Male
    b) Female
    c) Other
2. How old are you?
3. What is your nationality?
    a) Dutch
    b) German
    c) Other
4. What is your current occupation?
    a) Student
    b) Working
    c) Student and working
    d) other
5. What time in the day would be suitable for you to answer the daily survey between 18-22.00?

Appendix D

All Project Items with Original Formulation, Reformulation and Scale

Table C1. *All items used in daily diary questionnaire with item index, related construct, formulation and scale* f

Item	Construct	Formulation in accordance with DD design	Scale
P1	Positive emotions	I felt joyful today	0-10
P2	Positive emotions	I felt positively today	0-10
P3	Positive emotions	I felt content today	0-10
N1	Negative emotions	I felt anxious today	0-10
N2	Negative emotions	I felt angry today	0-10
N3	Negative emotions	I felt sad today	0-10
SE1	Self-esteem	On the whole, I was satisfied with myself today	1-4
SE2	Self-esteem	All in all, I was inclined to feel like a failure today	1-4
SE3	Self-esteem	I certainly felt useless today	1-4
SE4	Self-esteem	I feel that I had a number of good qualities today	1-4
MIL1	MIL - Presence	Today I understood my life's meaning	1-7
MIL2	MIL - Searching	Today I was searching for meaning in life	1-7
MIL 3	MIL - Significance	Today my life was full of value	1-7
MIL 4	MIL - Purpose	Today I was highly committed to certain goals in my life	1-7
MIL 5	MIL - Coherence	Today I could comprehend what my life is all about	1-7

PR 1	Positive relations with others	Today I received help and support from others when I needed it	0-10
PR2	Positive relations with others	Today I felt loved	0-10
PR2	Positive relations with others	Today I was satisfied with my personal relationships	0-10

Appendix E

MiL items with Original Formulation, Daily Diary Formulations and Original Questionnaire

Table D1.
Meaning in life items and their formulation in accordance with daily diary design and their original formulation and questionnaire

Item	Formulation in accordance with DD design	Original formulation	Original questionnaire
MIL1	Today I understood my life's meaning	I understand my life's meaning	MLQ (Steger et al., 2006)
MIL2	Today I was searching for meaning in life	I am searching for meaning in life	MLQ (Steger et al., 2006)
MIL 3	Today my life was full of value	My life is full of value	3DM (Martela & Steger, 2022)
MIL 4	Today I was highly committed to certain goals in my life	I am highly committed to certain goals in my life	3DM (Martela & Steger, 2022)
MIL 5	Today I could comprehend what my life is all about	I can comprehend what my life is all about	3DM (Martela & Steger, 2022)

Appendix F

RStudio packages used for analysis

```
library(tidyverse)

library(lubridate)

library(lme4)

library(nlme)

library(report)

library(sjPlot)

library(summarytools)
```

Appendix G

Adherence rate

Table F1

Adherence rate per participant for answering the mpath questionnaires and wearing the watch

Participant	Mpath Adherence (%)	Watch Adherence (%)	Overall Adherence (%)
10	86	85.4	
11	100	95.3	
12	100	92.2	
13	100	88.5	
14	100	85.4	
16	88	90.1	
17	50	88.5	
18	100	92.2	
20	100	89.6	
21	100	85.4	
22	100	84.9	
23	100	85.4	
24	88	89.6	
25	50	87	
26	100	87.5	
27	100	88.5	
28	100	94.4	
29	100	93.3	
30	100	90.1	
31	100	88	
32	100	87.5	
33	100	83.9	
34	100	84.4	
35	100	88	
36	88	87.5	
37	100	87	
38	75	87	
39	100	87.5	
40	100	87	
41	75	88	
42	88	85.7	
43	88	87.5	

200	88	85.7	
300	100	87	
Total	93.06	87.88	90.47