The Moderating Role of Types of Stressors in the Association Between Stress and Cognitive Function

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Abstract

Understanding the complex dynamics of stress is crucial to psychological research, as stress is associated with various physical and psychological health impacts. This study investigated the association between daily stress and cognitive function in everyday life and explored whether the type of stress moderates this association. The data was collected daily through the m-Path Sense app over a two-week period. Hereby, stress was measured by an adapted version of the Perceived Stress Scale-4, while cognition was measured through cognitive failures using the Questionnaire of Cognitive Failures in Everyday Life. The Type of stressor was assessed through participants' reports of their most unpleasant event of each day and categorised into interpersonal, work and school-related, and personal and lifestyle stressors. The sample (n = 8) consisted mostly of students older than 18 years and with sufficient English skills. A between-person analysis using multiple regression demonstrated no significant relationship between perceived stress and cognitive failures. Additionally, no significant moderating effect was found for types of stressors on this association. These findings are not in line with previous laboratory-based research. Nevertheless, this study demonstrates important methodological contributions for the research field as it used daily measurements in real-life settings to assess stress and cognition as well as valuable insights on stressor type categorisation.

Introduction

Stress is a prevalent issue in modern society with different long and short-term effects on people's mental health and wellbeing as well as their physical health (Pearlin & Bierman, 2013). Therefore, understanding the sources and underlying mechanisms of stress is crucial as their impacts can influence human functioning. Many researchers have investigated numerous aspects of stress and found that it can have many different effects on humans and their health (Zafar et al., 2021). For example, research found that stress not only directly affects the human body through physiological processes but also through individuals changing certain behaviours that influence their health because of stress, such as under- or overeating (Zellner et al., 2006). It is associated with negative impacts on heart rate and blood pressure, the immune system and the central nervous system, as well as on the quality of life (Zafar et al., 2021; Ribeiro et al., 2018). This already highlights the relevance of understanding stress mechanisms and their consequences. However, first, it is important to define stress and determine which kind of stress this study will focus on.

Defining Stress

Stress is a complex and multifaceted construct, and in psychological research, it is conceptualised differently depending on the context (Epel et al., 2018). On the one hand, it can be a life event or circumstance, which then can be called "stressor". On the other hand, it can refer to the biological, cognitive, and emotional response in the individual exposed to the stressors. This means stress can be understood as both stimulus and response (Epel et al., 2018). Traditionally, in the psychological field, stress is conceptualised as the relationship of the circumstances and their demands, and the individual's ability to manage and navigate the situation (Lazarus et al., 1985). This reaction to circumstances and its demands is stress as a response, usually including psychological components such as anxiety or feeling overwhelmed (Epel et al., 2018).

Within this multilevel stress framework that differentiates between stimulus and

response, as well as between affective, cognitive and physiological stress, it is also important to consider the duration and intensity of stress. Hereby, research defined daily hassles as relatively minor events that arise within people's day-to-day lives (Serido, 2004). These daily stressors include work deadlines, relationship conflicts and other daily challenges. As different studies have demonstrated that these daily stressors can predict mental and physical health outcomes more than major life events or chronic stress (Bolger et al., 1989; Eckenrode, 1984), this study will focus on examining everyday stress and its consequences. Furthermore, because there are not only psychological effects of stress responses but also physical or behavioural ones, there are various stress measures, such as behavioural coding or physiological measures (Crosswell & Lockwood, 2020). However, the easiest and most common way to measure psychological stress responses in daily life is to conduct self-report questionnaires on perceived stress (Crosswell & Lockwood, 2020).

Cognition

Stress was found to have an impact on cognition and processing through physiological processes in the brain (Zafar et al., 2021). Cognition is a broad concept which describes several processes (Sandi, 2013). These processes include perception and attention as well as executive control processes, memory processes and language (Sandi, 2013). The importance of understanding how stress might influence cognitive processes becomes clear when it is recognised that cognition essentially describes the processes that give humans the ability to speak, think, remember, learn from experiences and control behaviours (Batcha et al., 2019). Cognition is often measured in controlled environments such as laboratory experiments, however these settings cannot include the fluctuating factors of real-life settings that may influence cognitive processes (Carrigan & Barkus, 2016).

Cognitive failures specifically offer a way to measure cognition in everyday situations (Carrigan & Barkus, 2016). They are described as minor errors in thinking that interrupt the flow of the intended action. Such cognitive failures include forgetting what one was looking

for or being mentally overloaded during a conversation. Rather than measuring the direct cognitive performance of individuals, cognitive failures reflect real-life cognitive capacities and how effectively people can execute their cognitive processes in their everyday environment. This is particularly relevant when studying the impacts of stress on cognition because stress-related cognitive failures often manifest differently in everyday life than in controlled situations (Carrigan & Barkus, 2016).

Stress and cognition

Shields and colleagues (2016) examined acute stress effects on working memory, inhibition and cognitive flexibility in a meta-analysis. They found that stress impaired working memory and cognitive flexibility, however they did not find a main effect on inhibition. Their findings are interesting because they explore various existing studies on the association between stress and cognition, however all studies included in their meta-analysis were carried out in controlled environments. Furthermore, Sandi (2013) found that stress negatively impacts performance on memory tasks. They also reported that high acute stress negatively influences processes in the prefrontal cortex, which supports higher-order cognitive functions. Yet, they highlighted that stress intensity played an important role in the effect of acute stress on cognitive processes: mild stress tended to promote cognitive function (Sandi, 2013). Based on this empirical evidence it could be considered that higher stress levels could be negatively associated with cognition. As opposed to previous lab studies, a study by Sliwinski et al. (2006) investigated the relationship between daily stress in real-life settings and daily variability in cognitive performance. They found that daily stress negatively impacted participants' performances on attention-demanding tasks. Because this study worked with naturally occurring daily stressors instead of experimentally manipulated stressors, it is especially valuable. However, although the stressors are everyday life stressors, the assessment of cognitive function still took place in a lab environment in this study as well. The literature demonstrates findings that show a negative relationship between daily stress

and cognitive function, however there is a gap in studying the association of those variables in real-life everyday settings. This study will, therefore, explore the association of stress and cognition through daily measures.

Types of stressors

As mentioned before, the association between stress and cognitive function in everyday life could be influenced by different factors. People possibly react differently to a work overload than to a family argument. Therefore, one influencing factor might be the type of stressor that is experienced. When examining stressors in-depth, they can be distinguished across different domains, such as work and home (Serido et al., 2004). Almeida et al.'s (2002) study on daily stressors using the daily inventory of stressful events included the category 'content classification' to analyse the daily stressors. This category distinguishes between the stressor domains interpersonal tensions, work/education, home, finances, health/accident, network and miscellaneous. In their research on reactivity to daily stressors in adulthood, Hay and Diehl (2010) included the stressor domains interpersonal, home, network and health. Stefaniak et al. (2021) included in their study on age differences in types and perceptions of daily stress the stressor domains family/children, friends, spouse/partner, health, finances, and work/school. After reviewing these research papers on stressors, three categories of types of stressors were identified for this study. The first category is interpersonal stress, which includes family and spouse-related stress as well as personal and professional relationship challenges. Secondly, work and school-related stress is a domain that contains academic pressures for students and job-related stress for working individuals. The last category is personal and lifestyle stress. This category includes personal concerns, self-image issues and health issues, as well as home-related stressors and financial stress. Reducing the category size to only three domains compared to previous research has the purpose of minimising potential overlap between the categories. Having clear distinctions of categories is important to draw meaningful interpretations. Furthermore, due to a modest sample size in this type of

study a smaller number of categories attempts to ensure statistical power. When comparing the established types of stressors domains for this study to the categories of previous research on daily and acute stressors, it becomes apparent that all aspects are included.

In the analysis of the daily inventory of stressful events, researchers found that specific types of stressors were predictors of health symptoms and mood, namely interpersonal and network stressors (Almedia et al., 2002). Furthermore, a study on the effects of daily stress on negative mood has found that interpersonal daily stressors were the most influential compared to other stressors like overload at work and financial problems (Bolger et al., 1989). In this study, interpersonal conflicts accounted for over 80% of the explained variance in daily mood, and the effects were, in most cases, more than twice as large as other events. Although this study did not connect their result to cognitive performance, they highlighted that social conflicts lead to significant distress compared to other domains (Bolger et al., 1989). It has been found that mood can influence executive function in different ways (Mitchell & Phillips, 2007). Based on this research, it is reasonable to assume that interpersonal stress will demonstrate the strongest negative moderation effect on the association between stress and cognition. Secondly, a study on work stress and cognitive function found that young adults who are exposed to work stress have a decrease in cognitive function (Gafarov et al., 2021). Another study found that although work stress has a negative association with cognition, this effect only affected certain cognitive domains (Sindi, 2017). Although there is evidence for the negative association between work stress and cognition, research has also found evidence that work stress can improve some aspects of cognitive processes, like visual perception (Arji et al., 2022). This is also in line with the findings by Sandi (2013) that indicated that mild stress can also support cognitive function. A study by Gabrys et al. (2019) explores the association between stress and cognition in university students and finds that stress generally diminishes cognitive inhibition. However, they do not specify the stressor type as study-related stress. There is no previous research on how study-

related stress specifically impacts cognitive function. After reviewing previous research on work- and study-related stress, it is therefore postulated that work- and school-related stress will show a moderate negative moderating effect on the association of stress and cognition. Lastly, when considering personal and lifestyle stress, there is no specific previous research. This might be the case because personal and lifestyle stressors can include various topics. Although stressors like self-image and financial stress might have an important impact, based on the current knowledge, it is assumed that the effect is lower than in the other two categories. It is, therefore, assumed that personal and lifestyle stress will show the weakest moderating effect on the association between stress and cognition.

In summary, previous research has shown that stress can impact cognitive function significantly. While there have been many laboratory studies demonstrating that stress can impair cognitive functions like working memories, research on the association between naturally occurring stressors and cognition is very limited. This study aims to investigate the association of stress and cognition in daily life on smartphones to gain better knowledge for future interventions and programmes to prevent the negative impacts of stress on cognitive function. Additionally, different types of stressors might have varying impacts on cognitive function. Hereby, some evidence suggests that interpersonal stressors may impact psychological functioning more compared to other types of stressors. Therefore, this study also aims to address the question of whether the type of stressor moderates the association between perceived stress and cognitive failures, which are cognitive errors used to capture real-life cognitive functions. Based on previous research, it is assumed that the association between stress and cognition will be moderated by the type of stressor, with interpersonal stress showing the strongest negative effect. Furthermore, work and school-related stress is expected to show a moderate effect, and personal and lifestyle stress the weakest moderating effect.

Methods

Participants

This study was approved by the ethics committee of the University of Twente. Participants were recruited through convenience sampling and self-selection sampling via the SONA system for students from the University of Twente. When the participants were recruited through the SONA Systems website, they received a compensation of 3.5 to 4 SONA points (dependent on whether they were assigned to and participated in the usability and feedback interview after the study). Additionally, the researchers recruited participants in their personal environment through WhatsApp groups and Instagram stories. Because of the sampling techniques, a majority of the participants were university students. The inclusion criteria were participants over 18 years old and had sufficient language skills in English to understand the questions and tasks of the study. All participants who took part in this study had to confirm an informed consent form (Appendix A).

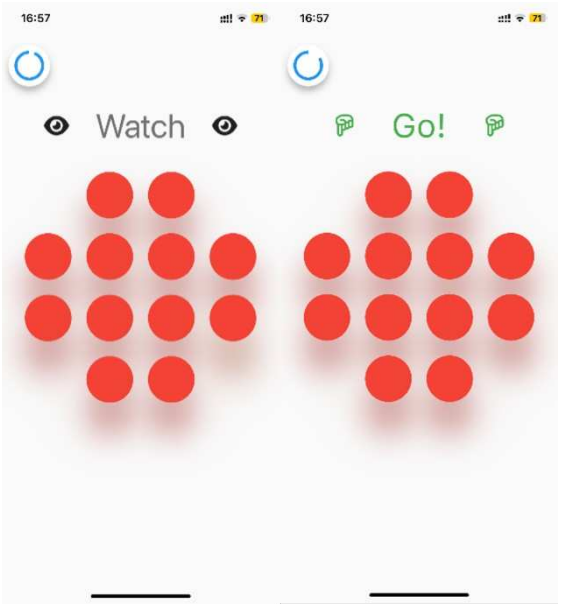
Materials

m-Path Sense

The m-path Sense application is the instrument through which the data is collected. The m-path app is a free platform for practitioners and clients (m-Path – Free Tool for Blended Care by KU Leuven, n.d.). It is designed for psychological treatment, and it includes tools to flexibly tailor the app according to the purpose of use. Therefore, it can be used for assessment through surveys and for interventions through, e.g. exercises (Figure 1). Hereby, the participant can fill out questionnaires and carry out tasks on the m-Path Sense app, and the researcher is able to monitor and collect the data via the online dashboard. This study is part of a bigger research project for which various questionnaires and cognitive tasks were implemented through m-Path Sense within the two-week period (Appendix A).

Figure 1

Example of the m-Path Sense Exercise Interface: Spatial memory task



Perceived Stress Scale-4

Stress was measured by an adaptation of the Perceived Stress Sale-4 (PSS-4; Cohen & Williamson, 1988). The PSS-4 consists of the items 2, 6, 7 and 14 from the original PSS. For this study, the items in the questionnaire were adapted from the original PSS-4. One example of the items used in this study is "Today I felt I was in control of the important things in my life". The participant was then able to rate their state from 'not at all' to 'Very much' on a slider with 0-10 points. Three of four items in this study required to be reverse scored, which resulted in higher scores indicating higher stress levels. Stress was tested once a day. The original PSS-4 demonstrates adequate psychometric properties, including reliability ($\alpha = .60$) and a one-factor structure that explained 45.6% of the total variance (Cohen & Williamson, 1988). Furthermore, the PSS-4 also shows adequate construct and predictive validity (Cohen & Williamson, 1988).

Cognitive questions

In this study, cognition was measured by an adaptation of the "Questionnaire of Cognitive Failures in Everday Life" (KFA). The KFA originally consisted of 13 items measuring attention lapses and memory deficits (Lange & Süß, 2014). The adapted questionnaire on cognitive failures in everyday life resulted in 4 items measured on a slider from 0-100, with zero meaning "not at all" and 100 meaning "very much". One example of the items is "In the past 2 hours, did your mind feel overloaded because of too much information? (e.g. feeling mentally overloaded during a conversation while multitasking)". Furthermore, the measurement of cognitive failures occurs four times per day. The original KFA demonstrates adequate psychometric properties with a split-half reliability (.80) and a one-factor structure that explained 39% of the total variance (Lange & Süß, 2014). The KFA also shows adequate convergent validity and construct validity (Lange & Süß, 2014).

Type of stressors

At the end of each day, each participant was asked to describe the most unpleasant and most pleasant event of the day. The most negative event of the day was used to determine the type of stressor for each day. The question is formulated in the following way: "Describe your day: What did you experience today? What was the most unpleasant situation? When was this? How did you handle this situation? (Also consider who you were with (first name and relationship to the person), where you were, and what you were doing). Would you like to type this in or speak up?". The participant was then able to either type or record their answer. After reviewing the answers by participants, each answer was categorised according to the types of stressors. These categories are 'Interpersonal stress' (IPS), 'Work and school-related stress' (WSS) and 'Personal and lifestyle stress'(PLS).

Procedure

After participants signed up for the study, they received further information on the study via email through an information sheet (Appendix B). Furthermore, within this email

contact, the researchers and participants agreed on a date and time for an introduction session via video call in which the researcher explained the installation and use of the m-Path Sense app with which the data collection was executed, as well as answered any additional questions. After that, the participants followed the instructions for filling out questionnaires and carrying out tasks on the app for two weeks. Each day of the two weeks, the participant received five notifications to fill out questionnaires and carried out tasks (Appendix A). The first prompt occurred at 7-8 am in the morning and did not expire until 2 pm because it assessed data on sleep quality, so it was adjusted so participants with different wake schedules were able to fill out the questions. After that, there were three EMA (ecological momentary assessment) questionnaires at 8-10 am, 12-2 pm, and 4-6 pm, each of which expired within one hour. They expired relatively quickly so that the current stress levels of participants could be assessed as accurately as possible. Between 10 and 11 pm, the last prompt of the day occurred. This evening questionnaire included additional questions such as “the most unpleasant event of the day” and took one hour to expire. The app continuously collected passive sensing data during the two weeks. During this time, the researchers monitored the data collection online and reminded participants to follow instructions in case their response rates were relatively low. After two weeks, the researchers randomly assigned 10 participants to take part in a final interview on the usability aspect of the m-Path Sense app.

Data Analysis

To analyse the research question ‘Does the type of stress moderate the association between stress levels and cognitive function?’ the data collected through the m-Path Sense app was analysed through the R studio statistical tool (R, n.d.). This study adopted a between-person analysis and focusses accordingly on how the association of stress and cognition might be affected by different types of stressors in different individuals. The first step was to standardise the variables, classify the written and spoken responses for the item of the most unpleasant event into the type of stressor variable categories and create averages of items that measure one construct. Stress was calculated by the mean of PSS scores across the 14 days for each participant. For this, it needs to be considered that the participants did not answer each notification they received, therefore the PSS average score is the mean value of all available data. Cognition was measured in the same way through a mean score of all available cognitive failure scores of each participant. Furthermore, for each participant, the most prominent type of stressor was assessed. Hereby, the prominent type of stressor is defined as the type of stressor that occurred the most often for each participant (the highest number of occurrences within the two weeks). Within this research design, stress is the independent variable that is expected to predict the dependent variable cognition. Furthermore, it is explored whether the type of stress (interpersonal, work/school-related, personal/lifestyle) has a moderating effect on the association of stress and cognition.

Next, the statistical assumptions of normality, linearity, homoscedasticity, Independence of errors, and multicollinearity were checked for the moderation analysis. A multiple regression analysis was carried out for the between-person analysis. For all statistical analyses in this study, a significance level of $p < .05$ was used to determine statistical significance.

Results

Descriptive statistics

The study included a sample of eight participants (n = 8), which consisted of three (37.5%) males and five (62.5%) females (Table 1). The age ranged from 19 to 27 (M = 23.4, SD = 2.7). While none reported formal diagnoses, four participants disclosed previous suspicions of mental health conditions: one reported suspected depression and anxiety, one reported suspected anxiety, one reported suspected ADHD, and one reported a suspected eating disorder. The response rates varied among participants, ranging from 25% to 81.9% (M = 58.3%, SD = 20.9%). Three participants showed response rates above 75% (SC004: 80.6%, SC006: 79.2%, SC007: 81.9%), while three participants had notably lower response rates below 50% (SC005: 40.3%, SC008: 45.8%, SC010: 25.0%) (Figure 2). Furthermore, the distribution of prominent stressor types showed that PLS was the most common type (50%), followed by IPS (25%) and WSS (25%). The mean score of PSS was 16.5 (SD = 6.24), with a minimum score of 8.92 and a maximum of 27.8. For cognitive failures was the mean score 16.5 (SD = 8.43), with a minimum score of 1.50 and a maximum of 26.6. To demonstrate the categorisation of stressors, consider the following three examples. This statement by participant SC006 was categorised with PLS: "Today i spent time helping my girlfriend move into her new appartement. The most unpleasant experience was having difficulties with stacking boxes the right way. They kept falling over. " An example of an answer matched to WSS is this answer by participant SC004: "most unpleasant today was the thought of the exam tomorrow. I tried to learn a bit but over all just went to distracting myself ". Finally, participant SC010's response exemplified the type of stressor IPS: "… I called my boyfriend to say good night and I felt like he cut the conversation short because he was watching a football game. I did not like the way this felt and got passive and reacted reproachfully".

Table 1

Demographics of the participants

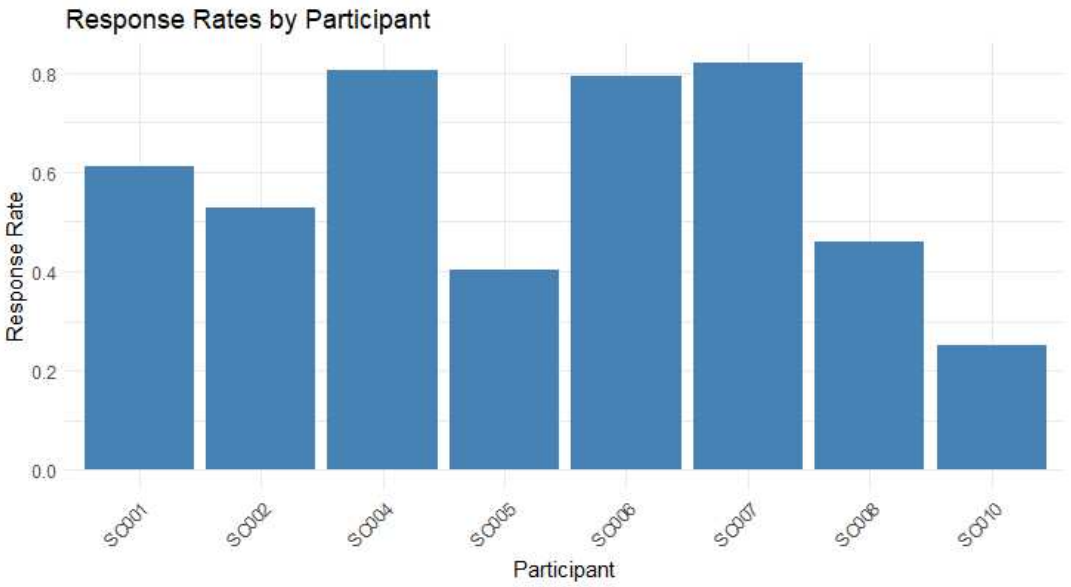
Demographics	Number of participants	Percentage (%)
Gender		
Males	3	37.5
Females	5	62.5
Suspected Mental Disorders/Conditions*		
Depression	1	12.5
Anxiety	2	25
ADHD	1	12.5
Eating Disorder	1	12.5

Participant ID	Response Rate in Percentage (%)	Prominent Type of stressor
SC001	61.1	IPS
SC002	52.8	PLS
SC004	80.6	WSS
SC005	40.3	PLS
SC006	79.2	PLS
SC007	81.9	WSS
SC008	45.8	PLS
SC010	25	IPS

Note. *Suspected disorders refer to conditions that participants reported concerns about or had undergone investigation for but had not received formal diagnoses. IPS = Interpersonal Stress, PLS = Personal and Lifestyle Stress, WSS = Work and School-related Stress.

Figure 2

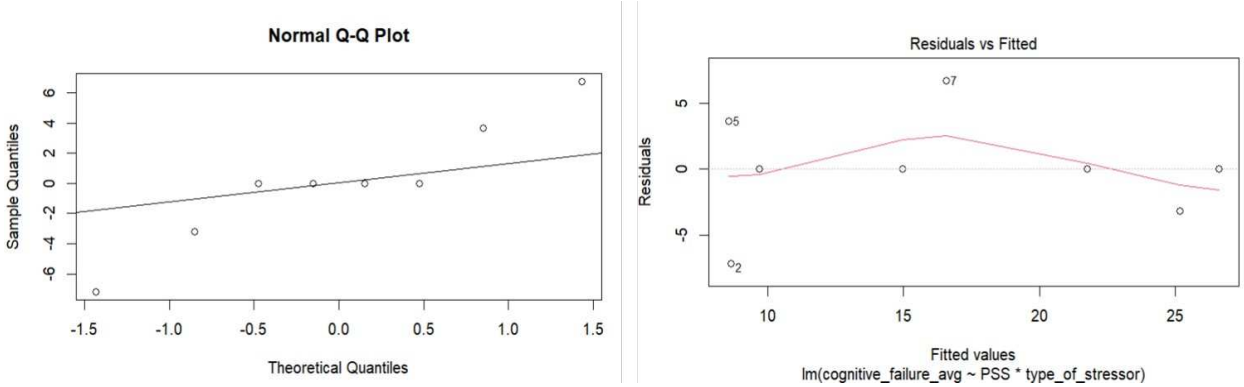
Response Rate Across Study Participants



The normality of the data for the multiple regression analysis was tested through a Q-Q plot of residuals, which showed no severe violations of normality. Furthermore, the linearity was tested through a residual versus fitted values plot (Figure 3). The plot had a slight curvature, which indicates a mild violation of the linearity assumption. Homoscedasticity was assessed through this plot as well, and inconsistencies were demonstrated across fitted values (Figure 3). This suggests a minor violation of this assumption. To test the independence of errors, the Durbin-Watson test was conducted and resulted in a value of 2.19 (p = .897), indicating that the residuals are independent, and this assumption was not violated. To assess the multicollinearity of the data, the Variance Inflation Factor (VIF) values were checked. The results showed VIF values of 7.04 for PSS, 9,145.60 for type of stressor, and 5,007.66 for their interaction term. As these values substantially exceed the threshold of 5, this indicates multicollinearity issues in the analysis. Given that the study is a pilot study with a very small sample size, the moderation analysis was conducted despite the violations of the assumptions. The results of the analysis need to be interpreted with great caution.

Figure 3

Diagnostic Plots for Multiple Regression Analysis: Normal Q-Q Plot and Residuals vs. Fitted Values Plot



Between-person Analysis

The main effects and interaction effects were tested through a moderation analysis for the between-person analysis. The linear model demonstrated that PSS had a negative, non-significant relationship to cognitive failures (b = -0.55, SE = 1.24, t = -0.44, p = .701) (Table 2). The analysis showed that the main effect of the type of stressor was not significant, F (2,2) = 0.29, p = .777 (Table 3). Moreover, the interaction effect between PSS and the type of stress was also not statistically significant, F (2,2) = 1.03, p = .493 (Table 3). When looking at the different stressor types compared to the reference category IPS, neither PLS (b = -40.7912, p = .326) nor WSS (b = 36.5189, p = .807) showed significant effects (Table 2). These results indicate that neither the perceived stress nor the type of stressor, independently or in combination, significantly influence cognitive failures. This suggests that the type of stressor does not significantly moderate the association between stress and cognition.

Table 2

Multiple Regression Results for Cognitive failures predicted my PSS and Type of Stressor

Predictor	**b**	**SE**	***t***	***p***
(Intercept)	37.09	29.62	1.25	.33

PSS	-0.55	1.24	-0.44	.70
Type of Stressor (PLS)	-40.79	31.64	-1.29	.32
Type of Stressor (WSS)	36.52	131.02	0.28	.80

Note. N = 8. R^2 = .759, Adjusted R^2 = .156. F(5, 2) = 1.26, p = .498. PSS = Perceived Stress Scale; PLS = Personal and Lifestyle Stress; WSS = Work and School-related Stress. IPS = Interpersonal Stress serves as the reference category for stressor type.

Table 3

Analysis of Variance Results for Effects of PSS and Stressor Type on Cognitive Failures

Source	**df**	**SS**	**MS**	**F**	***p***
PSS	1	219.59	219.59	3.66	.19
Type of Stressor	2	34.33	17.16	0.29	.77
PSS × Type of Stressor	2	123.44	61.72	1.03	.49
Residuals	2	119.84	59.92		.

Note. SS = Sum of Squares; MS = Mean Square; PSS = Perceived Stress Scale.

Discussion

This study investigated the association between daily stressors and cognitive failures in real-life settings and examined whether different types of stressors moderate this connection. Contrary to the expectations no significant association was found between perceived stress and cognitive failures. Surprisingly, the negative coefficient suggests that higher levels of perceived stress led to a direction of fewer cognitive failures. However, it merits attention that this finding is not significant. Furthermore, no significant moderating effect was found for the type of stressor associated with stress and cognitive failures. Interestingly, the regression analysis demonstrated that the reference category interpersonal stress was associated with more cognitive failures compared to personal and lifestyle stress (negative coefficient), which is also not in line with the assumption based on previous research. However, work and school-related stress was associated with more cognitive failures compared to the reference category interpersonal stress (positive coefficient). Although both directions are not significant, they show a contrasting pattern of personal and lifestyle stress and work and school-related stress. Hereby, it must be noted that due to the small sample size, there are high imbalances in the data, which results in low statistical power. The data contains substantial imbalances in the distribution of stressor types in the sample, in which 50% of the participants experienced predominantly personal and lifestyle stress and only 25% work and school-related stress. Also, interpersonal stressors were represented in the study by only 25%. This might reflect the daily challenges of the sample, which consists predominantly of students: managing personal and lifestyle overtook their attention compared to work and school-related challenges and interpersonal stress. As the measure of different types of stressors was self-reporting, in which they answered what their most unpleasant event of the day was, this distribution might also be explained by the nature of different stressors. Hereby, work and school-related stress could be more omnipresent, rather than one specific event that the participants consider mentioning. Furthermore, it needs to be considered that for

this analysis, the most prominent type of stressor for each participant was used to conduct a between-person study, which means that the measurements of different types of stressors within one participant were not taken into account.

The findings of this study contrast with the findings of previous laboratory studies, especially with the meta-analysis by Shields et al. (2016), which found significant impairments in working memory, cognitive flexibility and cognitive inhibition under stress conditions. Similarly, the results of this study differ from the findings by Sliwinski et al. (2006), as they found that daily stress predicted a decline in the performance of attention-demanding tasks. It must be noted, though, that they conducted a within-person study, and they suggest that daily stress measures might be better suited for studying short-term variations, which could explain the non-significant results of this between-person study with predominant types of stressors as a measurement. Another explanation of the differences between the results of this study and previous research could be the fundamental differences between measurements in controlled environments and real-life settings. Despite the high ecological validity, the measured observations in real-life settings may not be controlled for confounding variables, as it is the case in laboratory settings (Reis, 2018). This complexity of everyday environments could account for differing results.

For the role of types of stressors on the association between stress and cognition, the results are also not in line with the expectations. While Hay and Diel (2010) found heightened psychological reactivity to interpersonal stressors and Bolder et al. (1989) found that interpersonal stressors were significantly more influential to mood than other stress domains, the findings of this study showed no significant moderating effect of interpersonal stress to the association of stress and cognitive failures. Furthermore, Gafarov et al. (2021) found negative impacts of work stress on cognitive function, which is also not confirmed by the results of this study. Since personal and lifestyle stress is a category that was not previously mentioned in the research, there are no suitable comparisons to our results in this case. The

findings of this study, therefore, indicate that the association between stress and cognition, and the role of stressor types, might be more complex than previously theorised and that psychological reactivity may not directly translate to cognitive function.

Strengths

A major strength of this study lies in its high ecological validity using EMA with the m-Path Sense app. This method allowed the researchers to capture the stress and cognitive experiences of the participants in their natural environment, as well as the daily assessment to sufficient amounts of measurements for each participant. Furthermore, this method overcame the limitations and possible costs of laboratory-based assessment. Additionally, as the study was conducted online, it made it easier and more accessible for participants to take part in the study compared to laboratory-based studies. The same applies to researchers, as the online data collection process is timesaving and easily accessible, and the m-path Sense app allows data to be stored online directly. Another strength of the study is the combination of quantitative assessment through standardised questionnaires (PSS-4 and KFA) and qualitative measurements from the participants' own descriptions of their most unpleasant events to assess their main stressors, as it provided a multifaceted view of the participants' experiences. Lastly, one important strength of this study is that it has been unique in the field of studying the connection between stress and cognition to assess individuals' experiences in real-life settings. It needs to be highlighted that following this direction in future research makes it possible to gain valuable insights into studying psychological processes in everyday situations.

Limitations

There are several limitations that need to be considered when interpreting the findings of this study. First, it is important that due to this study being a pilot study, the small sample size of eight participants limits the statistical power substantially. This results in the difficulty

of detecting meaningful effects. Within the assumption testing, some violations were detected that could also impact the statistical power and the reliability of the results: The assumption of multicollinearity was violated. This suggests a potential overlap of the predictor variables perceived stress and type of stressor. Furthermore, there are considerable differences in response rates between the participants, ranging from 25% to 81.9%. Therefore, the findings might not represent the participants' experiences accurately. A participant with a low response rate might have experienced a different stressor predominantly, however it was not reported.

When examining the types of stressors in depth, it also becomes clear that choosing the most prominent stressor for each participant might falsely represent the diverse experiences of the individuals. For example, participant "SC001" experienced interpersonal stress on six occasions and work and school-related on four occasions. This resulted in the prominent stressor interpersonal stress, although 40% of their most unpleasant experiences were work and school-related stress. Furthermore, some participants had responses that were not clearly categorizable. For example, Participant SC001 reported an unpleasant event of an interpersonal challenge with their supervisor within a work setting. They misread an email from their supervisor and realised that the supervisor might be more upset than they expected. This stressor was categorised as interpersonal stress as it was interpreted as that the focus of the stressor laid mainly on the relationship between the participant and their supervisor, so the interpersonal conflict. However, it could be argued that because they experienced a work/university-related challenge, the correct category would be work and school-related stress. Another case of this would be an answer of Participant SC007, who described that one day, they did not sleep well and woke up tired and stressed. They explained further that they had to study but experienced difficulties standing up. This experience was categorised as personal and lifestyle stress, as it seemed that the focus was that they did not sleep well and had difficulties standing up. On the other hand, it could also be interpreted as study stress, which would lead to the categorisation of work and school-related stress. It becomes apparent

that there might be too much room for interpretation between the individual experiences of the participants and the categorisation of stressors. Lastly, another limitation worth mentioning is that the sample consisted mainly of students, which therefore makes the findings not representative of the whole population. Due to their age and circumstances, students might have different experiences of and reactions to stress. For example, Ribero et al. found that university students belong to a sociodemographic age bracket in which stress-associated disorders are more prevalent (2017).

Implications and Future Research Directions

As this study was a pilot study with a considerably small sample size, it became apparent that a larger sample size is necessary to replicate this study. This will ensure higher statistical power for detecting potential effects and higher reliability of the findings. Second, it could be valuable to develop strategies that might increase the response rates of participants to ensure that the collected data represents the individuals' real-life experiences accurately. This could be done by adjusting the notification schedule or introducing monetary rewards for higher response rates. Furthermore, in future research, it would be constructive to reconsider the type of stressor categorisation. Hereby, after reviewing the results of this study, it could be argued that a larger amount of more specific categories, like in previous research by Almeida et al. (2002) and Stefaniak et al. (2021), might represent individuals' experiences more accurately. Additionally, it would be valuable to define keywords or phrases that suggest a specific category beforehand to minimise the room for interpretation during the analysis. Another recommendation for future studies is to either determine a specific target group, such as university students or to choose sampling methods differently to establish higher representativeness of the whole population.

For this study, a between-person analysis was chosen, however it could reveal meaningful insights in future research to also analyse within-person variations. This could result in different findings as then, for each person, the effect of each type of stressor on the

association between stress and cognition could be analysed instead of the one most prominent stressor. Also, there might be interesting insights through the exploration of different individuals' fluctuations of stress levels and cognitive performance over time. Furthermore, for a within-person analysis, the reporting of suspected or diagnosed mental disorders or conditions would be of greater interest. It could be explored whether the association of stress and cognition behaves differently in individuals with, for example, ADHD. ADHD symptoms were found to be positively associated with perceived stress (Combs et al., 2015). Therefore, it poses the question of whether the association between stress and cognition also presents itself differently than in neurotypical individuals. Additionally, individuals with different mental disorders or conditions might also differently react to different types of stressors. As stress could even cause or worsen disorders depending on the type of stressor and duration of stress (Esch et al., 2002), it would be especially valuable to explore further how stress and stressor types might affect individuals with mental illness.

Conclusion

The aim of this study was to explore the association between daily stress and cognition in real-life settings, with a particular focus on how different types of stressors might moderate this link. There were no significant association between perceived stress and cognitive failures found, nor was there a moderating effect of types of stressors on the association. However, important methodological contributions have been established. The implementation of EMA through the m-Path sense app demonstrated a unique approach to studying psychological processes in everyday situations. While a small sample size and low statistical power limited the detection of potential effects, this pilot study highlights important considerations for future studies, especially in the categorisation of different stressor types and the complexity of capturing individuals' real-life experiences. To summarise, the insights of this study on EMA and the type of stressor categorisations are important and valuable for future research in the field of studying the association between stress and cognition in natural settings. This development of methodology may contribute to future research into better understanding the association of stress and cognition as well as how different types of stressors might influence this connection. Recognising underlying factors and mechanisms as well as consequences in real-life settings is essential as stress is a prevalent and modern societal issue with various health impacts. This knowledge is crucial for developing effective interventions to reduce stress and its effects on humans' health and wellbeing.

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Appendix A

Intake questionnaire

Once as an intake

Introduction & informed consent:

Welcome to the study: **The Dynamics of Stress and Cognition with Mobile Sensing**! This study is being done by **Xiaochang Zhao** from the Faculty of Behavioural, Management and Social Sciences (BMS) at the University of Twente.

The purpose of this research study is to **understand the relationship between stress and cognition in daily life** using a combination of mobile questionnaires, tasks, and passive sensing (e.g., location, phone use). Additionally, we seek to **evaluate the usability and feasibility of these methods for tracking cognitive changes in everyday life.**

In the next two weeks, you will receive five notifications daily, prompting you to complete brief questionnaires and tasks spread throughout the day. During this period, passive data (see information sheet) will be collected continuously to capture daily activity patterns. It is important that you answer the questionnaires **as soon as possible**. Please make sure that you **turn on the notifications for the m-Path Sense app** on your smartphone. At the end of the study, you might be selected and invited for a 30-minute interview to discuss your experiences and provide feedback. The data of this study will be used for publications.

Your participation in this study is entirely voluntary and you can withdraw at any time without providing a reason. We believe there are no known risks associated with this research study; however, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. This means that your data will only be accessible within the research team. All personal data will be coded, encrypted, and stored separately from other types of data.

Taking part in the study

1. I have read and understood the study information, 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).

2. 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).

3. I understand that taking part in the study involves an introductory session, two-week daily questionnaires, and a video-recorded interview (if selected). The video recordings in the interview will be transcribed as text, and the recording will be destroyed after transcription (Yes/No).

Use of the information in the study

4. I give permission to process the survey responses, passive sensing data (see information sheet) and transcribed interview collected during this study (Yes/No).

5. I understand that information I provide will be used for publications (Yes/No).

6. 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).

7. I agree that my information (anonymized) can be quoted in research outputs (Yes/No).

8. I agree to be video recorded in the interview if selected (Yes/No).

Future use and reuse of the information by others

9. I give permission for the anonymized survey responses, passive sensing data (see information sheet) and transcribed interview that I provide to be archived in p-drive of the University of Twente so it can be used for future research and learning (Yes/No).

Demographics:

Thank you for filling out the consent form! Before we begin, we would first like to ask a few questions about your background.

1. What is your age? (Please enter your age in years)(Open question)

2. What is your gender?

- 1. Male
- 2. Female
- 3. Non-binary
- 4. Prefer not to say
- 5. Prefer to self-describe:____

3. Have you been diagnosed with any of the following conditions? (please select all that apply and specify where indicated) (Multiple Choices):

- 1. Depression
- 2. Anxiety disorder
- 3. Attention Deficit Hyperactivity Disorder
- 4. Learning disorder (e.g., dyslexia, dyscalculia)
- 5. Speech or language disorder (e.g., stuttering)
- 6. Autism
- 7. Motor disorder (e.g. dyspraxia)
- 8. Obsessive-Compulsive Disorder

- 9. Schizophrenia
- 10. Other neuropsychiatric condition: ____
- 11. None of the above
- 12. I prefer not to disclose

4.(Any option except 11 & 12 selected in the last question) Are you currently taking medication for any of these conditions?

- 1. Yes.
- 2. No.
- 3. I prefer not to disclose.

5. Have you had any concerns or investigations for any of the conditions listed above (but were not diagnosed)?

- 1. Yes, please specify: ____
- 2. No.
- 3. I prefer not to disclose.

6. What is your home address (Street, city, ZIP code)?

- 1. Please specify: ____
- 2. I prefer not to disclose

7. What is your work address (Street, city, ZIP code)?

- 1. Please specify: ____
- 2. Not applicable
- 3. I prefer not to disclose

8. What is your school address (Building, Campus, University)?

- 1. Please specify: ____
- 2. Not applicable
- 3. I prefer not to disclose

9. What is the model of the smartphone you are currently using for this study (e.g. iPhone 15)? (Open text box)

10. What is the operating system of the smartphone you are currently using for this study?

- 1. Android
- 3. iOS

Practice trials for cognitive tasks:

Thank you for your response! You will be asked to perform three short tasks on screen during the daily prompts. Now you will go through the practice trials of these tasks. Feel free to ask the researcher if you do not understand the task instructions.

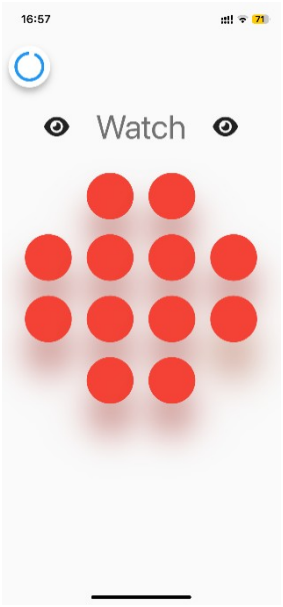
Spatial working memory task-Part 1: Forward condition

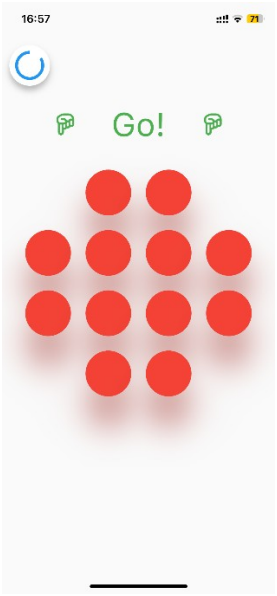
Task description:

Welcome to the first task! There are two parts of this task. On your screen, you will see many circles. Some of the circles will light up in a specific order. Pay attention to the order in which the circles light up. Once the sequence is finished, you need to tap the same circles **in the same order**. The sequences will increasingly get longer. Press "next question" to start!

Spatial working memory task-Part 2: Backward condition

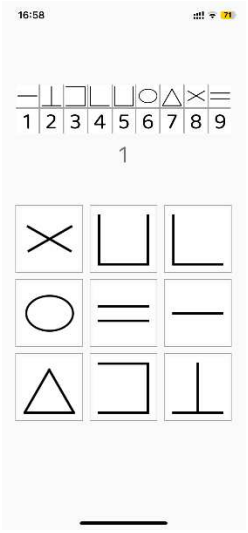
Task description: Now comes to the second part of this task: On your screen, you will see many circles. Some of the circles will light up in a specific order. Pay attention to the order in which the circles light up. Once the sequence is finished, you now need to tap the same circles **in the reverse order**. The sequences will increasingly get longer. Press "next question" to start!





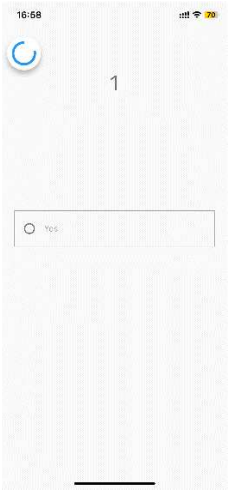
Digit Symbol Substitution Test (DSST)

Task description: Now comes to the second task! On the top of your screen, you will see a set of matching rules where symbols are matched with numbers. You will also see a number presented in the middle of your screen. You need to match this number to a symbol according to the rule. This task will last for 30 seconds. Please respond as quickly and accurately as possible. Press "next question" to start!



2-back task

Task description: Welcome to the third task! You will be presented with a series of numbers. Starting from the third number, a button saying "yes" will be provided: if the number you see equals the number you were shown two screens before, press it. This task will last for 30 seconds. Please respond as quickly and accurately as possible. Press "next question" to start!



Full sensing set up:

Thank you for your response! The data collection using your phone sensors will now begin and continue throughout the 2-week study period. You can expect to receive 5 short prompts per day to complete. Please respond as many as possible when you receive these prompts.

1. [Full sensing set up]

Sleep questionnaire (adapted from Consensus Sleep Diary)

1xper day

1. What time did you close your eyes to go to sleep? (Time)

2. How long did it take you to fall asleep? (Time)

3. Approximately how long did moments of wakefulness last during the night? (Time)

4. What time did you wake up in the morning? (Time)

5. How would you rate the quality of your sleep? (Slider:0-10; Very poor-very good)

EMA Questionnaire

3x per day

<u>Affective state:</u>

1. At this moment, my positive feelings are (slider: not at all strong-very strong;0-100)

2. At this moment, my negative feelings are (slider: not at all strong-very strong; 0-100)

<u>Self-perceived stress:</u>

3. At this moment, I feel stressed (slider: not at all-very much; 0-100)?

4. At this moment, I feel tense (slider: not at all-very much; 0-100)?

5. At this moment, I feel energetic (slider: not at all-very much; 0-100)?

Cognitive failures in everyday life (adapted based on KFA; Lange & Süß; Cognitive failures questionnaire version 1& 2)

1. In the past 2 hours, did you have trouble making up your mind? (e.g. deciding between options, making a choice at work or home) (Slider:0-100; not at all-very much)?

2. In the past 2 hours, did your mind feel overloaded because of too much information? (e.g. feeling mentally overloaded during a conversation, while multitasking)

3. In the past 2 hours, did you find you could not think of anything to say? (e.g., having a mental block, struggling to find the right words in conversation or when asked a question)

4. In the past 2 hours, did you make mistakes in simple tasks that you wouldn't normally make because of being distracted? (e.g. small errors like miscounting, forgetting something, misplacing items, or making typing mistakes)

Mobile passive sensing validation questions

The following questions ask about the information related to your phone sensors.

1. (Location) Where are you now?

- 1. Home
- 2. Work
- 3. School
- 4. Café/Restaurant
- 5. Store (e.g., supermarket, mall)
- 6. Outdoors (e.g., park)
- 7. Traveling (e.g., in a car, on a bus)
- 8. :____

2. (Location, if school was chosen in the last question) Which building are you in? If you are not at the University of Twente, please select "Not applicable".

- 1. Capitool
- 2. Citadel
- 3. Gallery/Design lab
- 4. Horst
- 5. Langezijds
- 6. Not applicable.
- 7. Ravelijn
- 8. Spiegel

- 9. Sports centre
- 10. Technohal
- 11. Vrijhof (library)
- 12. Waair
- 13.:____

m-Path get location

3. In the past hour, did you keep your phone with you most of the time (e.g. pocket, bag, in hand)? (Yes/No)

4. In the past hour, where did you keep your phone most of the time?

- 1. Pocket
- 2. Bag/Purse
- 3. In hand
- 4. Attached to the body (e.g. belt clip, arm band)
- 5.: ____

5. (Activity, if yes to question 4) In the past hour I have walked around ...% of the time while carrying my phone (Slider:0-100).

6. (Activity, if yes to question 4) What mobility activities did you do in the past hour while carrying your phone (Multiple choices)?

- 1. Walking
- 2. Running
- 3. Cycling
- 4. Driving a car
- 5. Sitting
- 6. Other, namely:____

6. (App use) What smartphone apps have you used in the past 15 minutes?

- 1. WhatsApp
- 2. Instagram
- 3. Facebook
- 4. Twitter (X)
- 5. Outlook

- 6. Gmail
- 7. Spotify
- 8. Netflix
- 9. Google Maps
- 10. Duolingo
- Other, namely:____

8. (Noise) How loud is the sound around you (Slider: Silent-Noisy; 0-100)?

m-Path get Noise level

9. (Battery level) What is the current battery percentage of your phone (Slider: 0-100)?

10. (Battery charge) Is your phone currently charging (Yes/No)?

Cognitive tasks

Spatial working memory task-Part 1: Forward condition

Task description:

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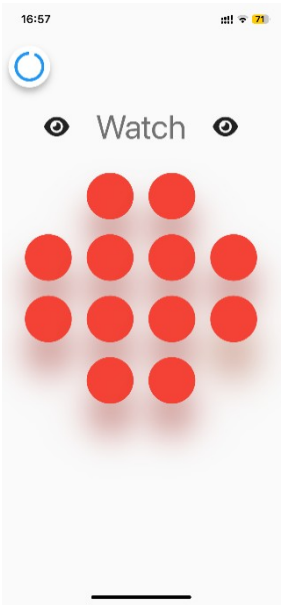
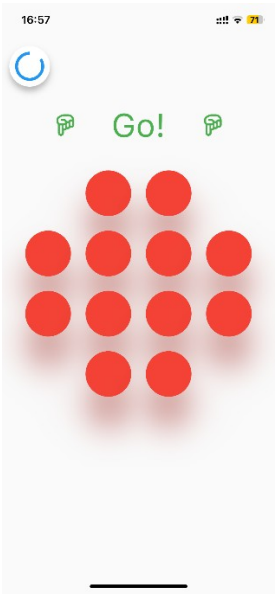
Spatial working memory task-Part 1: Backward condition

Task description: Now comes to the second part of this task: On your screen, you will see many circles. Some of the circles will light up in a specific order. Pay attention to the order in which the circles light up. Once the sequence is finished, you now need to tap the same circles **in the reverse order**. The sequences will increasingly get longer. Press "next question" to start!





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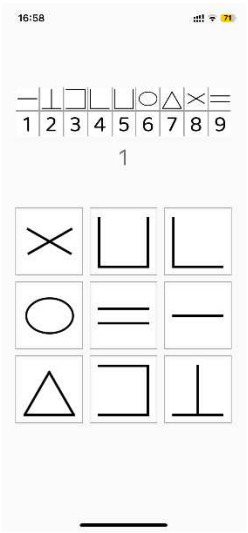

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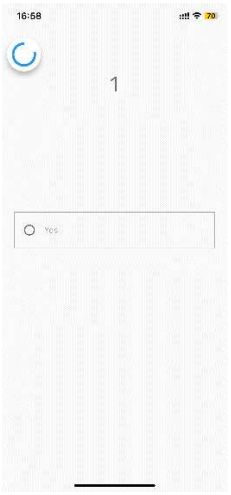

Evening questionnaire

1x per day

EMA questionnaire + the following questions:

<u>Events of the day (Negative)</u>

1. Describe your day: what did you experience today? What was the most unpleasant situation? When was this? How did you handle this situation? (Also consider who you were with (first name and relationship to the person), where you were, and what you were doing). Would you like to type this in or speak up?

- Typing
- Speaking

<u>Coping appraisal/processing of unpleasant events</u>

2. How did you think about this situation (Multiple choices)?

- 1. I tried to think of a solution.
- 2. I worried about it.
- 3. I kept thinking about it.
- 4. I tried to look at it in a positive way.
- 5. I tried to accept it.
- 6. I tried not to think about it.
- 7. I stopped thinking about it.
- 8. Other, namely...

3. What did you do with this situation (Multiple choices)?

- 1. I tried to resolve it

- 2. I told someone about it
- 3. I expressed my feelings about it
- 4. I tried to suppress my feelings
- 5. I tried to relax
- 6. I did nothing about it
- 7. Other, namely…

4. I felt I had an influence on this situation (Slider: No influence at all-A lot of influence; 0-10)

5. This situation was unexpected (Slider: Not at all unexpected- Very unexpected; 0-10)

Events of the day (Positive)

6. Describe your day: what did you experience today? What was the most enjoyable situation? When was this? How did you handle this situation? (Also consider who you were with (first name and relationship to the person), where you were, and what you were doing). Would you like to type this in or speak up?

Coping appraisal/processing of pleasant events

7. How did you think about this situation (Multiple choices)?

- 1. I thought back on it with pleasure
- 2. I thought back on it in a negative way
- 3. I tried not to think about it
- 4. I stopped thinking about it
- 5. Other, namely...

8. What did you do with this situation (Multiple choices)?

- 1. I told someone about it
- 2. I enjoyed it
- 3. I expressed my feelings about it
- 4. I tried to suppress my feelings
- 5. I tried to distract myself by doing something else
- 6. I did nothing more about it
- Other, namely…

9. I felt I had an influence on this situation (Slider: No influence at all-A lot of influence; 0-10)

10. This situation was unexpected (Slider: Not at all unexpected- Very unexpected; 0-10)

Physical complaints

11. Today I felt physical discomfort (e.g. fatigue, flu, headache, backache, tinnitus, tension, hay fever, menstrual pain)

a. [if yes] What kind of physical discomfort (multiple complaints possible)?

b. [if yes] I suffered from these complaint(s) (not at all - a lot)

Perceived stress scale (PSS)

12. Today I felt I was in control of the important things in my life (Slider: Not at all-Very much;0-10)

13. Today I felt confident to deal with personal problems (Slider: Not at all-Very much;0-10)

14. Today I felt like things were going my way (Slider: Not at all-Very much;0-10)

15. Today I felt that difficulties were piling up so high that I could not overcome them (Slider: Not at all-Very much;0-10)

Stopping passive sensing

Thank you for your participation!

This is the end of the 2-week data collection. All mobile sensors are now turned off. The researcher will contact you to inform you whether you have been selected for an interview.

1. [Passive sensing with all sensors off]

Appendix B

Information Sheet

Dear participant,

Welcome to the study **The Dynamics of Stress and Cognition with Mobile Sensing,** of the Section of Psychology, Health and Technology (PHT) of the University of Twente, under the project Stress in Action (SiA).

It is important that you learn about the procedure of this study before it starts, so please read the following text carefully. If anything is unclear to you, feel free to ask the researchers directly, or contact them through email: stress-cog-study@utwente.nl. The researchers will be happy to answer any questions you may have.

Goal of the study

The aim of this study is to understand how daily stress and cognition are related in daily life using a combination of mobile questionnaires, tasks, and information collected by phone sensors (e.g., location, phone use). Additionally, we seek to evaluate the feasibility and usability of these methods for tracking cognitive changes in everyday life.

Procedure of the study

This study will begin with a 30-minute introductory session (online or in-person) to explain the study and set up the smartphone app we will use for data collection (m-Path Sense). You will also fill in the informed consent, an intake questionnaire and practice trials for tasks via the m-Path Sense app.

Over the next two weeks, you will receive five notifications daily, prompting you to complete brief questionnaires and tasks throughout the day. The first questionnaire (1 minute), delivered in the morning, will ask about your sleep. The next three questionnaires (5 minutes), sent throughout the day, will ask about affect, stress, cognition, location, activity, app use, phone battery and ambient noise. During this questionnaire, you will also be asked to activate your momentary location and ambient noise in your environment. The final evening questionnaire (8 minutes) will include questions from the earlier prompts and additional items on daily events, physical complaints and overall daily stress. In addition to the questionnaires, passive data (e.g., location, phone use) will be collected continuously during the two weeks to capture daily activity patterns.

At the end of the study, 10 participants will be randomly selected and will be invited for a 30-minute interview to discuss your experiences and provide feedback. This interview will be video-recorded.

Who can participate?

To participate in this study, you must a) be at least 18 years old; b) understand English at a sufficient level; c) use an iOS or Android phone as your primary phone in daily life.

Compensation

You will be rewarded with 4.5 SONA research credits, when you complete the entire study without the interview. If you are invited for the interview, additional 0.5 SONA research credits will be rewarded.

What passive data will be collected?

Below is the overview of the types and frequency of data collected by phone sensors during the 2-week period.

Type of data	Description	iOS	Android	Frequency
Location	GPS coordinates every minute.	Yes	Yes	iOS: every 10 meter moved; Android: continuous
Device	Information about your device (e.g.: name, version, available working memory, battery level).	Yes	Yes	Continuous
Weather	Weather and air quality from the internet based on current location.	Yes	Yes	Continuous
Pedometer	Number of steps according to the pedometer of your mobile phone.	Yes	Yes	Continuous
Activity	Number of minutes walking, cycling, driving, etc.	Yes	Yes	Event (change of activity such as still or walking)
Screen	Time of screen on/off/unlocked events.	No	Yes	Event (with screen off or on).
Battery	Amount of battery left, if battery is charging or not.	Yes	Yes	Event (e.g. starting to start charging)
App usage	Usage time per app since the last measurement.	No	Yes	Continuous
Connectivity	Connected to Wi-Fi or data.	Yes	Yes	Event (e.g. connecting to Wi-Fi)
WIFI	Wi-Fi networks in the vicinity.	Yes	Yes	Continuous
Accelerometer	Accelerometer (acceleration)	Yes	Yes	Continuous
Ambient noise	Volume (in decibels) of ambient noise. No audio is saved.	Yes	Yes	Only when asked to activate

For the data collected from the smartphone, we will not have access to the specific content of that data. For instance, we can track that a particular app is being used, but we cannot see what actions were taken or what was viewed within the app. For GPS coordinates, we are not focused on your exact addresses or specific locations. Instead, we aim to determine whether they align with the places you have reported visiting, allowing us to see if the app can accurately detect when you are near these locations. Additionally, the locations will be grouped into broader categories, such as "restaurant" or "park," rather than identifying individual places.

Risks

We believe there are no known risks associated with this research study. However, as with any online related activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. This means that your data will only be

accessible within the research team. All personal data will be coded, encrypted, and stored separately from other types of data. The video recordings in the interview and audio recordings from the survey responses will be transcribed as text, and the recording will be destroyed after transcription. This research project has been reviewed and approved by the **BMS Ethics Committee**, University of Twente.

Withdrawal from the study

Your participation in this study is voluntary: you are not obligated to participate. You may decide to stop your participation during the study, and you can also decide to withdraw after the study. You do not have to provide a reason for stopping. If you decide to withdraw, your data will no longer be used for the research and will be completely deleted. You can indicate directly to the researcher that you wish to stop or withdraw from participation via email. Please note that you can withdraw from the study up to 2 months after your participation. After this period, the data will have been anonymized, meaning we will no longer be able to link the data to your identity. As a result, it will not be possible to delete your data once this process is complete.

Retention period

Research data will be retained for minimally 10 years.

Further information

If you have any questions about the study, either before you participate or afterwards, please feel free to contact the responsible researcher: Xiaochang Zhao via stress-cog-study@utwente.nl. If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), or if you want to file a complaint about this study, please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl.

Appendix C

AI Statement

During the preparation of this work the author used Claude AI (https://claude.ai) in order to Brainstorm, summarise literature on the topic, for copy-editing, receiving feedback on structure, checking grammar, and flow of the text, and assisting in programming code for R Studio. After using these tools/services, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.