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Daily sleep in relation to subjective and physiological stress in an occupational context: Daily vigour as a mediator

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Abstract

Studies on the stress-sleep relationship consistently demonstrate negative effects of stress on sleep. The reversed relation, however, has received less research attention. Also, field studies on physiological stress are scarce. The aim of this day-level diary study was to examine daily relationships between sleep quality and quantity, and subjective and physiological stress in an occupational context. Moreover, we examined daily vigour as an underlying mechanism of the sleep-stress relationship. Participants were 167 knowledge workers who filled in daily questionnaires measuring sleep quality and quantity, morning vigour and subjective afternoon stress on Tuesdays and Thursdays for 5 weeks. Physiological stress was assessed with cortisol decline from morning peak to evening, and with blood pressure in the afternoon. Multilevel path analysis results showed that better sleep quality and longer sleep hours predicted increased vigour the following morning, which in turn predicted lower subjective stress in the afternoon. Sleep quality and quantity were not related to physiological stress neither directly nor indirectly via morning vigour. On the basis of our results, sleep should be considered as a factor affecting vigour which in turn seems to lower stress.

KEYWORDS
blood pressure, cortisol decline, day-level relations, sleep, stress, vigour

1 | INTRODUCTION

Previous studies in the occupational context have consistently demonstrated a negative effect of perceived stress on sleep (Linton et al., 2015; Litwiller et al., 2017). More recently, attention has shifted towards reciprocal longitudinal relationships: Stress does not only have an impact on sleep but sleep may have an effect on subsequent stress in the long-term (e.g., Garefelt et al., 2020; Van Laethem et al., 2015; Åkerstedt et al., 2015). In addition, existing diary studies have found better sleep quality and longer sleep hours to predict emotional well-being and lower levels of stressors on the following day (e.g., Lee et al., 2017; Sin et al., 2017). Experimental studies show that sleep deprivation lowers the threshold at which a person experiences an event as stressful (e.g., Minkel et al., 2014).

Next to the direct relationship between sleep and stress, considering possible underlying mechanisms is vital for our understanding of the sleep-stress relationship. To our knowledge, this issue has not been examined in the sleep-stress relationship. One potential underlying mechanism in the sleep-stress relationship could be how vigorous employees feel when waking up in the morning. Sleep is a critical part of the recovery process that restores daily energy levels (Åkerstedt et al., 2009). If someone wakes up well-rested and physically and mentally energized, they feel motivated about going to work, and show optimal psychological functioning during the day (Shirom, 2010), and consequently, may be less stressed during that day. We approach stress not only as a subjective experience but also as a physiological reaction, which broadens the view of stress prevailing in most field studies. It also enables us to explore their mutual relationship, which is often implied but has turned out to be inconsistent (Brown et al., 2020).

The contributions of the present study are threefold. First, although there has been a steady increase in studies on the relationship between sleep and stress (Zhao et al., 2021), we still lack an in-depth understanding of the sleep-stress relationship. We contribute to this understanding by exploring daily vigour as an underlying mechanism. Second, we provide a more complete view of the stress construct by including both subjective (self-reported) and physiological measures (cortisol decline and blood pressure) of daily stress, enabling us to study their mutual relationship. Third, our findings also benefit practitioners by providing suggestions for evidence-based interventions. In this regard, a key question is whether efforts to improve occupational well-being should exclusively target stress or whether, in fact, it would be effective to focus on improving sleep, which may also improve employees' stress levels.

2 | Daily sleep in relation to subjective and physiological stress in an occupational context

Sleep quality and quantity are related but distinct aspects of sleep that are both important for employee health and functioning (e.g., Barnes, 2012; Litwiller et al., 2017; Van Laethem et al., 2016). Sleep quality refers to an overall evaluation of the nature of one's sleep upon awaking and is based on such aspects as difficulty/ease of falling asleep, maintaining sleep throughout the night, and feeling well-rested upon awakening (Kohyama, 2021; Litwiller et al., 2017). Sleep quantity refers to the duration of a sleep period (e.g., Kohyama, 2021; Van Laethem et al., 2016). It is important to take into account both sleep quality and quantity given that they are rather weakly correlated and may differ in their relationship to many outcomes (Litwiller et al., 2017). Nevertheless, sleep quality and quantity may also have parallel effects on outcomes such as health and well-being (Barnes, 2012; Cappuccio et al., 2010). Kohyama (2021) concludes in his review that sleep quality, rather than sleep quantity, is reflecting health or functioning issues.

The sleep-stress relationship can occur for many reasons (Sonnentag, Binnewies et al., 2008). As poor sleep hinders replenishment of energy resources, persons have fewer resources available after a night of poor sleep, and therefore they may report higher stress. After a night of poor sleep, persons may anticipate problems in goal attainment (for example, due to difficulties to concentrate) and the need to invest compensatory effort to attain their goals. Such an anticipation will increase negative affect, such as stress. The relationships described above can theoretically be explained by the conservation of resources (COR) theory, especially relying on processes related to resource losses (Hobfoll, 1998; Shirom, 2010). The COR theory posits that individuals feel stressed when essential resources are threatened to be lost, are actually lost, or when effort is expended which does not result in acquiring new or regaining lost resources (Hobfoll, 1998; Hobfoll & Shirom, 2001). Resource losses also have the tendency to accumulate and to form chains of resource losses. Accordingly, poor sleep is expected to increase vulnerability to further resource loss. As poor sleep means energy loss, it diminishes the ability to gain resources and is reflected in increased stress levels (resource loss).

There exist both long-term and short-term evidence in favour for the sleep-stress relationship. For example, over a 2-year period disturbed sleep predicted subsequent higher perceived work demands and stress, and less social support and control (Åkerstedt et al., 2015). Difficulties maintaining sleep and non-restorative sleep predicted increased levels of perceived work demands and stress in another study (Garefelt et al., 2020). From a short-term perspective, daily diary studies have revealed that good sleep quality is positively related to positive affect (positive activation and serenity), and negatively related to negative affect (negative activation and fatigue) experienced the next morning (Sonnentag, Binnewies et al., 2008). Better sleep quality and, to a lesser degree, longer sleep duration have predicted emotional well-being and lower stressors on the following day (Sin et al., 2017). Moreover, short sleep hours and poor sleep quality have led to perceptions of more work-to-family conflict and time inadequacy on the next day (Lee et al., 2017).

Based on this theoretical and empirical evidence we hypothesise:

Hypothesis 1 *Poor daily sleep, indexed by a) poor sleep quality and b) short sleep quantity, is related to subjective stress on the following work day.*

Good sleep quality and quantity are essential for daily functioning (e.g., Brossoit et al., 2019) and human health and well-being (e.g., Åkerstedt et al., 2009). Stress refers to a subjective and physiological state of high arousal and displeasure (Kristensen et al., 1998). Thus, stress comprises a subjective experience (assessed with self-reports) and a physiological reaction to the environment, which can be captured with physiological stress markers such as blood pressure, heart rate or stress hormones like epinephrine, norepinephrine, and cortisol (for a review, see Ganster & Rosen, 2013). Two physiological stress systems that are imperative for stress recovery are the hypothalamic-pituitary-adrenal (HPA) axis and the sympathetic-adrenal-medullary (SAM) system (Ganster & Rosen, 2013). In the present study, cortisol and blood pressure were used as physiological stress markers. Cortisol is an outcome of the HPA-axis and blood pressure is tied to the SAM-system.

Cortisol levels follow a diurnal rhythm. Specifically, cortisol levels rise for the first hour after awakening and then gradually decline until midnight (Clow & Hamer, 2010). Studies suggest that a low (flattened) awakening response, a low cortisol decline throughout the day since the peak (CDD) and high cortisol levels at bedtime can indicate poor stress recovery and suboptimal functioning, that is, feelings of stress, exhaustion and dissatisfaction (e.g., Chandola et al., 2010; Chida & Steptoe, 2009; McEwen, 1998). In the present study, we focussed on daily cortisol decline, because we were interested in whether sleep could be associated with stress recovery on the following work day.

Sleep onset, nocturnal awakenings, and sleep duration are known to influence the profile of the next day cortisol diurnal rhythm (see Balbo et al., 2010, for a review). More specifically, diary studies showed that reduction in sleep quality and feeling less rested in the morning predicted a slower cortisol decline during the day among women with diagnosed breast cancer (Tell et al., 2014). In another diary study by Dahlgren et al. (2009) high evening levels of cortisol were associated with symptoms of stress and fatigue and poor self-rated health but not with sleep. A cross-sectional study among civil servants revealed that both short sleep duration and sleep disturbances were independently associated with a slower rate of decline of cortisol levels across the following day (Kumari et al., 2009).

There are reviews showing that both poor sleep quality and short sleep hours are associated with higher blood pressure (Lo et al., 2018; Makarem et al., 2019, 2021). For example, the review by Lo et al. (2018) indicates that poor sleepers had higher average blood pressure than normal sleepers. The review by Makarem et al. (2019) concluded that a significant association between short sleep duration and elevated blood pressure is found more often in studies using self-reported sleep duration than studies using objectively measured sleep duration. Nevertheless, in the study by Doyle et al. (2019) shorter actigraphy-derived sleep duration was associated with higher daytime and nighttime blood pressure, and shorter sleep duration on one night was associated with higher blood pressure the following day.

Although there is lack of diary studies on sleep-physiological stress relationship and there also are studies which have not supported the review findings presented above, we hypothesise:

Hypothesis 2 *Poor daily sleep, indexed by a) poor sleep quality and b) short sleep quantity, is related to physiological stress (i.e., slower cortisol decline, higher blood pressure) on the following work day.*

3 | Vigour as an underlying mechanism

Research has not yet looked at possible underlying mechanisms of the sleep-stress relationship. One potential mechanism—vigour—is a construct of energy and characterized in the occupational context by feeling energized and enthusiastic about one's job as well as looking forward to work when getting up in the morning (Breevaart et al., 2012; Shirom, 2010). Vigour, and good sleep, can be considered resources in line with the COR theory (Hobfoll, 1998; Shirom, 2010). Accordingly, good sleep has the potential to facilitate gaining vigour. This occurs via replenishing depleted energy resources during a good night's sleep. Conversely, poor sleep may decrease feelings of vigour and thereby constitute a loss of resources, which in turn may result in increased stress levels throughout the day.

Of the relationships theorized above based on the COR framework, some have gained empirical evidence. First, good sleep quality is linked to work engagement (Barber et al., 2013; Schleupner & Kühnel, 2021), of which vigour is a key dimension (Shirom, 2010). After nights employees slept better, they indicated higher vigour or vitality during the day (Clinton et al., 2017; Kühnel et al., 2017; Schmitt et al., 2017). Second, highly engaged and vigorous employees reported more positive affect and less negative affect at the end of a work week compared to their less engaged counterparts (Sonnentag, Mojza et al., 2008). Third, after an acute psychological stress task workers with higher work engagement showed lower blood pressure than those with lower work engagement (Black et al., 2017). Nevertheless, in another study vigorous managers did not differ from burned-out managers in HPA-axis functioning (Langelaan et al., 2006).

On the basis of the theoretical reasoning above and incomplete empirical evidence, we propose the following:

Hypothesis 3 *Low daily vigour mediates the positive relationship between poor daily sleep, indexed by a) poor sleep quality and b) short sleep quantity, and subjective stress on the following work day.*

Hypothesis 4 *Low daily vigour mediates the positive relationship between poor daily sleep, indexed by a) poor sleep quality and b) short sleep quantity, and physiological stress (slower cortisol decline, higher blood pressure) on the following work day.*

4 | METHOD

4.1 | Participants

The data were collected in Finland as a part of a larger research project aiming to test whether completing a 15-min lunchtime relaxation exercise or a park walk would benefit employee well-being (de Bloom et al., 2017; Sianoja et al., 2018). We reached out to 2226 people working in knowledge-intensive jobs in which the role of knowledge in product and service delivery is a key aspect. In total, 279 employees expressed their interest to participate, yielding a response rate of 12.5%. In order to have at least two people in each study group (park walk, relaxation, and control group) from each organisation (7 in total), we excluded organisations that had less than six volunteered participants. This reduced the number of participants down to 225. In addition, some participants dropped out before the study ($n = 48$) or during the study ($n = 5$) due to conflicting schedules, sickness, and other reasons. Additionally, we excluded 5 participants because most of their data were missing. After these dropouts, 167 participants remained. We did not pay any financial compensation for the partipaction, but we delivered personal feedback on the results for each participant. Additionally, we raffled three travel vouchers (worth 400€ in total) among all participants and everyone was invited to attend a lecture after the study had ended regarding the benefits of the natural environment and applied relaxation exercises. The intervention activities are described in detail elsewhere (de Bloom et al., 2017).

Participants (n = 167) were mainly female (90%) and aged between 25 and 62 (M = 47.5 years, SD = 8.8). Most were married or lived with a partner (83%) and over half (55%) had children living at home. Participants were highly educated (62% held a bachelor's degree or higher) and worked in various sectors with the most common sectors being public administration (48%) and education (29%). The majority held a permanent employment contract (90%), worked full-time (96%) and on day shift (100%), which was a criterion for participation. The ethnicity of all participants was white/Caucasian.

4.2 | Procedure

We collected the data in two phases in spring and fall of 2014. Each data collection lasted 6 weeks, two of which were intervention weeks. Before the study, we asked participants to fill in an online questionnaire with general information such as demographics. Daily subjective and physiological measurements were completed on Tuesdays and Thursdays over five working weeks, altogether on 10 days. A short text message (SMS; Short Message Service) -questionnaire was sent to participants' cell phones in the afternoons about 1 h before they usually left work. Participants also completed a paper-and-pencil booklet each day. SMS-reminders were sent on Monday and Tuesday evenings to remind the participants that they should take saliva samples, blood pressure measurements and fill in the questionnaires on Tuesday and Thursday mornings. Before the study started, researchers visited participants' workplaces in order to explain the study protocol, practice the park walk or relaxation exercises and provide in-person instructions on how to take the blood pressure measurements and collect saliva samples. Additionally, participants received these same instructions in written format. All participants provided written informed consent, and they were informed of the voluntary nature of the study participation. The full protocol has been published elsewhere (de Bloom et al., 2014) and the study protocol was duly approved by the Ethics Committee of Tampere Region, Finland.

4.3 | Within-person level measures

4.3.1 | Sleep quality and quantity

Daily sleep quality ('How well did you sleep last night?'; 1 = *very poorly*, 5 = *very well*) and sleep quantity ('How many hours did you sleep last night?') were assessed with one item each. Both were measured each morning in the brief paper-and-pencil questionnaire. Similar one-item measures have been used in several studies (e.g., Dahlgren et al., 2009; Hahn et al., 2011; Sin et al., 2017), and shown to correlate highly with longer sleep measures (Hahn et al., 2011).

4.3.2 | Subjective stress

Daily subjective stress was measured in the afternoon via a SMS-questionnaire with one item ("'Right now, at the end of my work day, I feel stressed and tense'; 1 = *strongly disagree*, 7 = *strongly agree*). The measure was adapted from Elo et al. (2003) and shown to measure subjective stress in a reliable and valid way (Elo et al., 2003; Fisher et al., 2016).

4.3.3 | Physiological stress

To assess the activation of the HPA-axis, we measured CDD. CDD was calculated based on two cortisol values: The peak response in the morning (AW30) minus the evening cortisol value (E). In our study the peak cortisol (AW30) was measured 30 min after wakeup in the morning and the evening sample was collected at bedtime (right before going to sleep). A steeper cortisol decline from the peak until evening (= larger CDD value) indicates better recovery or lower stress. Participants were asked to report the time of collecting each sample. The participant-reported average sample collection times across all measurements was 6:56 AM (SD = 0:41) for the peak cortisol measure and 10:03 PM (SD = 0:56) for the evening cortisol measure. Participants used Salivette swabs to self-sample cortisol from saliva at home. They stored the saliva samples in their home refrigerators until we collected the samples from their workplace. We mailed the samples to the Finnish Institute of Occupational Health, where they were analysed. A LIA kit (LIA, IBL, Hamburg, Germany) was used to analyse the values of salivary cortisol (reported in nmol/l). Cortisol data were transformed using natural logarithm transformation.

Blood pressure, reflecting the SAM-system activity, was measured as mean arterial pressure (MAP), assessed in the afternoon (the average measurement time across all measurement days was 3:34 PM, SD = 1:07) at the workplace using Omron M2 digital blood pressure monitors (displayed as mmHg). Two blood pressure measures collected at a two-minute interval were averaged as they were highly correlated (r = 0.84–0.92, $p < 0.001$), and resulted in a diastolic and a systolic blood pressure value. Participants wrote down the values of blood pressure measurements in a paper-and-pencil booklet. They were asked to rest for 5 min before each blood pressure measurement. In order to calculate MAP, diastolic blood pressure was first doubled and then added to the systolic blood pressure. Next, the resulting value was divided by three (Curtis et al., 2007).

We carefully inspected the cortisol and blood pressure data to ensure the validity of measurements. First, participants with a diagnosed psychiatric disease (n = 4) or endocrine diseases (n = 26) were removed from the cortisol sample. These exclusions resulted in a final cortisol sample of 137 participants. Second, regarding the blood pressure data, participants who had diagnosed hypertension and systematically had blood pressure values higher than two SDs over our sample average were removed from the data. Thus, the blood pressure sample included 162 participants.

In addition, regarding the cortisol data, we identified participants who showed a negative or systematically very flattened awakening response profile (i.e., less than 2.5 nmol/l rise from awakening to 30 min after awakening on more than 50% of the days [n = 38]). These so-called CAR non-responders did not show awakening response, suggesting that their values could be biased due to an undiagnosed illness of the adrenal glands, having a habit of snoozing in bed (i.e., continuing to sleep in the morning after the alarm clock first goes off) or reaching the peak cortisol rise later than the 30 min collection time (Wüst et al., 2000). Due to possibly biased cortisol values, we took into account in the analyses, whether the participant was a CAR responder or CAR non-responder.

In order to minimize the effects of any confounding variables, we asked the participants not to eat, drink (alcohol or anything besides water), exercise, or brush their teeth 30 min before each saliva sample collection and blood pressure measurement. To monitor compliance to the research protocol, we asked the participants to indicate if they had engaged in these behaviours and write down the exact time of collecting each sample or measurement in a paper-pencil booklet.

Based on the information about these confounding variables, participants' single cortisol and blood pressure values were removed, if non-adherence to the protocol (e.g., alcohol consumption before taking the sample, engaging in strenuous physical exercise before taking the sample, taking the sample outside the recommended time frame, outliers beyond 3 *SDs* from the sample mean) was observed. Altogether, 1339 single values out from 4110 values in total (3 measurements per day × 10 days × 137 participants) were removed from the cortisol data (32.6%), and 202 values out from 19,440 values in total (systolic and diastolic values × 2-min repeated measurement × 3 times per day × 10 days × 162 participants) were removed from the blood pressure data (1.04%).

4.3.4 | Morning vigour

Daily morning vigour was assessed retrospectively in an evening paper-and-pencil questionnaire with one item ('This morning, I felt like going to work'; 1 = *strongly disagree*, 5 = *strongly agree*) adapted from the vigour scale of the short Utrecht Work Engagement Scale (UWES) by Schaufeli et al. (2006). In Finnish studies (altogether 16,335 participants), this item has strongly loaded (loadings over 0.80) on the short vigour scale consisting of three items in confirmatory factory analyses (Hakanen, 2009). One of the three items ('At my work I feel full of energy') seems to have a good face validity, with which the item we used correlates highly, as shown by high Cronbach alpha of the scale. The Cronbach alpha of the three-item vigour scale varied across 10 countries (altogether 15,521 participants) between 0.60 and 0.88 (median = 0.77) in the study by Schaufeli et al. (2006) originally validating the short UWES scale. Therefore, we think the chosen item reflects the construct of vigour in the occupational context well.

4.4 | Control variables within-person or between-person level

At the within-person level, we controlled for the intervention type. We asked the participants to confirm whether they went for a walk ('Did you go for a walk during your lunch break?'; 0 = *No*, 1 = *Yes*) or performed a relaxation exercise ('Did you engage in relaxation exercises during your lunch break?'; 0 = *No*, 1 = *Yes*) during their lunch break in the evening paper-and-pencil questionnaire.

At the between-person level, we controlled for whether the participant was a CAR non-responder (= 0) versus CAR responder (= 1).

4.5 | Statistical approach

Intra-class correlations indicated that between 54% and 74% of the variance in study variables was at the day level (i.e., within individuals). Only the intra-class correlation of MAP was somewhat lower, showing that 31% of variance was at the day level. Thus, using a multilevel approach to the data was justified. To account for the nestedness of several daily measurements within individuals, all hypotheses were tested using multilevel path modelling in Mplus 7.4 using maximum likelihood estimation (Muthén & Muthén, 2015). The FIML (full information maximum likelihood) method available in Mplus, which takes all data into account without imputing data, was used to handle missing data.

All study variables varied at the within-person (i.e., $N_{\text{Level 1}}$: 1221–1504 data points) and between-person level (i.e., $N_{\text{Level 2}}$: 167 participants). Concerning CDD, 851 data points were available. As we were exclusively interested in day-level relations, all hypothesized relationships were modelled at the within-person level. The predictors (sleep quality and quantity) were person-mean centred (cf. Aguinis et al., 2013). The within-person level control variables (walk and relaxation exercise) were entered as two separate dummy variables (0 = *no walk/relaxation exercise*, 1 = *walk/relaxation exercise*). The between-person level control variable CAR non-responder/responder was also entered as a dummy variable (0 = *CAR non-responder*, 1 = *CAR responder*). The mediator (vigour) and outcome variables (subjective stress, MAP, and CDD) were not centred as they needed variance at both levels (cf. Binnewies et al., 2010).

Model fit was assessed using the root mean square error of approximation (RMSEA), comparative fit index (CFI), and standardized root mean square residual (SRMR). RMSEA values below 0.07, CFI values above 0.95, and SRMR values below 0.08 indicate acceptable model fit (Hu & Bentler, 1999; Steiger, 2007). To test our hypotheses, we estimated one multilevel model. We checked that the within-person sample size was sufficiently powered for a model of this complexity. A post hoc power analysis with G-Power (Faul et al., 2007) indicated that with the number of daily observations in our study, a small effect size ($f = 0.1$) and an alpha error probability of 0.05 should have resulted in a power of 0.83. Thus, we concluded that the model was indeed sufficiently powered. Direct pathways from sleep quality, sleep quantity, and the two control variables to the stress outcomes (i.e., subjective stress, MAP, CDD) were modelled. Additionally, pathways from sleep quality and quantity to morning vigour as well as pathways from vigour to the three stress measures were added to the model. Finally, the control variable CAR non-responder/responder was modelled as a predictor of CDD at the between-person level.

To test whether daily vigour mediates the association between sleep quality and quantity on the one hand, and subjective and physiological stress on the other hand, we calculated the indirect effects with Bayesian estimation in Mplus 7.4 (using default starting values). To assess effect size of mediation effects we calculated the proportion mediated (dividing indirect effect by total effect) following recommendations by Fairchild et al. (2009). The recent mediation methods do not expect a direct relationship between an independent and a dependent variable. They also give more accurate estimates than traditional methods (e.g., the Baron & Kenny approach). In addition, due to the multilevel nature of our data, traditional methods for assessing mediation were inappropriate. The assumption of independence of observations is violated when clustered data are used, consequently leading to downwardly biased standard errors (e.g., Preacher et al., 2011).

5 | RESULTS

5.1 | Descriptive statistics

Means, standard deviations, intra-class correlations, and correlations are presented in Table 1. Looking at the within-level measures, participants reported moderately high sleep quality, and sleep duration ranged from 5.4 to 8.5 h per night (M = 7 h per night). A sleep duration of approximately 7–9 h per night is considered healthy (Hirshkowitz et al., 2015). Nevertheless, participants reported less than 7 h per night on approximately half of the nights (47.3%). They reported to be moderately stressed and vigorous. However, the range of subjective stress and vigour varied considerably (almost across the whole scale). Regarding blood pressure, participants had a healthy MAP score (between 70 and 100; Veltkamp et al., 2017) on 82.0% of the days. On the other days, MAP was high with a maximum of 116. CDD largely varied between −0.8 (a flattened CDD profile, indicating more stress during the day) and 72.7 (a steep CDD profile, indicating less stress during the day). Overall, participants seemed to be rather healthy with the exception of short sleep duration.

Within-person level correlations show that a part of the correlations were in line with our expectations. Both sleep quality and sleep quantity were not correlated with subjective stress and physiological stress indicators (i.e., MAP, CDD), but were positively associated with vigour. Vigour was in turn negatively correlated with subjective stress, but not with MAP and CDD. Subjective stress was positively associated with MAP, but not with CDD.

5.2 | Hypothesis testing

Standardized estimates are reported unless stated otherwise. To test our hypotheses concerning daily sleep, subjective and physiological stress, and morning vigour, all study variables and control variables were simultaneously entered into one multilevel path model. This model fitted the data very well ($\chi^2(8)$ = 11.951, CFI = 0.99, RMSEA = 0.02, $SRMR_{within}$ = 0.01, $SRMR_{between}$ = 0.05). The between-person level control variable (CAR non-responder vs. responder) predicted CDD ($\gamma = 0.38$, $p < 0.001$), revealing that CAR responders had steeper cortisol decline, that is, less physiological stress and better recovery. We also performed all analyses without CAR non-responders: the overall results (available from the first author) remained the same. The within-person level results (including CAR non-responders) are presented in Figure 1.

TABLE 1 Means, standard deviations, intra-class correlations, and correlations of study variables

	M	*SD*	ICC	1.	2.	3.	4.	5.	6.	7.	8.
1. Control walk (% yes)	14.6%				−0.01	0.03	−0.01	−0.06	−0.05	−0.04	0.06*
2. Control relaxing (% yes)	12.9%			−0.46**		−0.01	−0.02	−0.10**	−0.06	−0.03	0.02
3. Sleep quality (1–5)	3.48	0.62	0.26	−0.03	−0.08		0.43**	−0.01	−0.04	0.01	0.24**
4. Sleep quantity (in hours)	6.99	0.58	0.34	−0.11	0.05	0.18		−0.01	−0.03	0.01	0.17**
5. Subjective stress (1–7)	3.82	1.09	0.29	0.04	−0.01	−0.28**	0.02		0.18**	0.02	−0.15**
6. MAP	93.01	7.48	0.69	−0.02	0.18	0.03	0.01	0.07		−0.06	−0.04
7. CDD	25.92	13.52	0.35	−0.01	0.08	−0.19	0.01	0.05	0.02		−0.03
8. Vigour (1–5)	3.68	0.74	0.46	−0.09	0.09	0.43**	0.09	−0.48**	0.05	−0.12	
9. CAR responders (% yes)	77.2%			0.11	0.01	−0.01	−0.01	0.18*	−0.07	0.40**	−0.15

Note: N = 165–167 individuals (N_{CDD} = 137), N = 1221–1504 data points (N_{CDD} = 851). Correlations above the diagonal are within-person level correlations and correlations below the diagonal are between-person level correlations.

Abbreviations: CDD, cortisol decline from morning peak until evening; ICC, intra-class correlation; *M*, mean; MAP, mean arterial pressure; *SD*, standard deviation.

$^*p < 0.05$, $^{**}p < 0.01$.

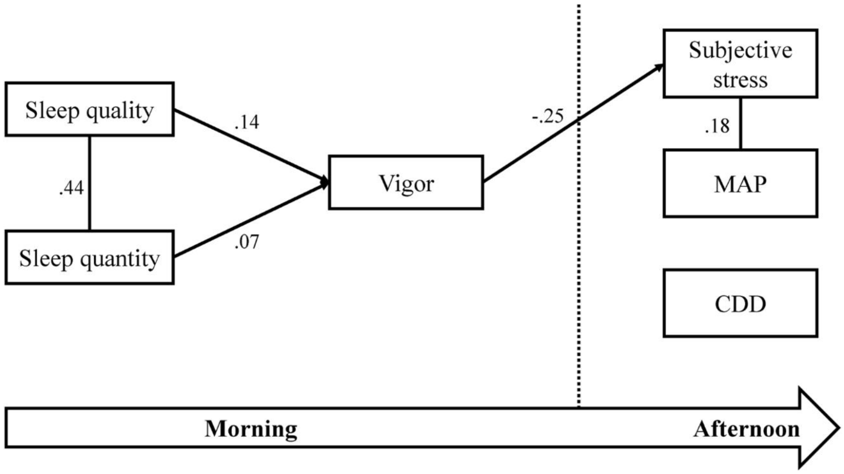

FIGURE 1 Within-person level results of the multilevel path model. For clarity only significant pathways are depicted and pathways from control variables to stress outcomes were excluded. The control variables (walk and relaxation exercise during lunch break) were not significantly related to subjective or physiological stress, except for a negative relation between relaxation exercise and subjective stress ($\gamma = -0.10$, $p < 0.01$). MAP, mean arterial pressure; CDD, cortisol decline from morning peak until evening

5.2.1 | Daily sleep in relation to subjective and physiological stress

The first aim of the study was to examine the direct day-level relationships between sleep quality and quantity and subjective and physiological stress. Figure 1 reveals that the day-level relationships between sleep quality and subjective and physiological stress (MAP and CDD) were non-significant (sleep quality-subjective stress: $\gamma = 0.02$, $p = 0.545$; sleep quality-MAP: $\gamma = -0.01$, $p = 0.849$; sleep quality-CDD: $\gamma = 0.03$, $p = 0.539$). Thus the multilevel path model did not support hypotheses 1a and 2a. The results also revealed that sleep quantity was not related to subjective stress ($\gamma = 0.02$, $p = 0.485$) or physiological stress (sleep quantity-MAP: $\gamma = -0.01$, $p = 0.675$; sleep quantity-CDD: $\gamma = 0.02$, $p = 0.691$). These findings did not support hypotheses 1b and 2b.

5.2.2 | Vigour as an underlying mechanism

The second aim of this study was to examine whether morning vigour acts as a mediator in the daily sleep-stress relationship. The multilevel path model (Figure 1) revealed that sleep quality ($\gamma = 0.14$, $p < 0.001$) and quantity ($\gamma = 0.07$, $p < 0.05$) were both positively associated with vigour the following morning. On work days when participants reported to have slept better and longer, they also felt more vigorous the next morning. Daily vigour, in turn, was negatively related to subjective stress ($\gamma = -0.25$, $p < 0.001$). On work days when participants felt more vigorous in the morning, they reported experiencing less stress in the afternoon. Daily vigour was not related to physiological stress markers (vigour-MAP: $\gamma = -0.04$, $p = 0.421$; vigour-CDD: $\gamma = -0.08$, $p = 0.097$).

Results of the multilevel mediation analysis indicated a significant indirect relationship between sleep quality and subjective stress (unstandardized estimate = −0.060, 95% CI [−0.096, −0.031], $p < 0.01$; total effect = −0.026, $p = 0.658$). Vigour fully mediated the relationship between sleep quality and subjective stress. When participants slept better the previous night, they reported lower stress in the afternoon and this relationship could be explained by increased morning vigour. Likewise, vigour acted as a mediator in the relationship between daily sleep quantity and subjective stress in the afternoon (unstandardized estimate = −0.037, 95% CI [−0.075, −0.005], $p < 0.05$; total effect = 0.012, $p = 0.872$). Vigour fully mediated the relationship between sleep quantity and subjective stress. On work days when participants slept longer, they felt less stressed during the afternoon, which could be explained by increased vigour in the morning. Thus daily vigour mediated the relations of sleep quality and sleep quantity with subjective stress, supporting hypotheses 3a and 3b. As daily vigour was not related to physiological stress, it could not act as a mediator in the relationship between sleep quality or quantity and physiological stress. Thus hypotheses 4a and 4b were not supported.

5.2.3 | Supplemental analyses: The role of optimal sleep duration

As previously noted, a sleep duration of approximately 7–9 h per night is considered healthy (Hirshkowitz et al., 2015). To further explore whether optimal sleep duration (compared to suboptimal sleep duration) was also predictive of subsequent daily vigour and stress, sleep quantity was recoded and entered as a dummy variable (0 = *suboptimal sleep duration either less than 7 h or more than 9 h*, 1 = *optimal sleep duration between 7 and 9 h*). All results were identical to the hypothesised results presented above. Optimal sleep duration was positively related to morning vigour ($\gamma = 0.06$, $p < 0.05$), which in turn was negatively associated with subjective stress in the afternoon

($\gamma = -0.25$, $p < 0.001$) but not with physiological stress indicators MAP and CDD. Daily morning vigour did almost fully mediate the relationship between optimal sleep duration and subjective stress (90% proportion mediated; unstandardized estimate = −0.043, 95% CI [−0.09, −0.004], $p < 0.05$; total effect = −0.048, $p = 0.652$). It is noteworthy that only five values of sleep quantity were higher than 9 h of sleep per night. Thus, in this exploratory analysis optimal sleep duration is mainly compared to short sleep duration.

6 | DISCUSSION

Using the framework of COR theory, the aim of the present daily diary study was to shed new light on the sleep-stress relationship by examining in an occupational context whether daily vigour constitutes an underlying mechanism in transmitting the effects of sleep on stress. We took into account both sleep quality and quantity and subjective and physiological stress (cortisol decline, blood pressure). The results showed that both sleep quality and quantity were related to afternoon subjective stress through morning vigour. However, sleep quality and sleep quantity were not related to physiological stress neither directly nor indirectly via morning vigour.

6.1 | Daily sleep, stress, and vigour as an underlying mechanism

Our results shed light on the short-term relationship of sleep quality and quantity with subjective and physiological stress. Even though previous studies have found evidence linking sleep quality and to lesser extent sleep quantity to subsequent stress (Lee et al., 2017; Sin et al., 2017; Sonnentag, Binnewies et al., 2008), in the present study this direct relationship was not replicated. This difference may relate to different measures of subjective stress used in the earlier diary studies. We measured feeling stressed in the afternoon at a certain moment, whereas in the studies mentioned above negative affect (including distress) in the morning or during the whole day or daily stressors in the past 24 h were in the focus. Therefore, perhaps in our study the participants' stress levels measured real-time in the afternoon at work were mostly affected by the immediately preceeding work-related events and less by sleep during the preceding night. However, at the between-person level good sleep quality during last night and feeling less stressed in the afternoon were related to each other. It is also interesting to note that many participants slept less than 7 h half of the time, suggesting that working people may often lack sleep during regular working times.

We did not find a significant relationship between sleep and the physiological stress marker blood pressure either, although the relationships have been detected in different studies concerning especially sleep duration (see Makrem et al., 2019, 2021, for reviews). Also, no relationship between daily sleep and cortisol decline was found, contrary to findings from some previous diary studies (e.g., Tell et al., 2014). When CAR non-responders were excluded from the dataset, the relationship between daily sleep quantity and cortisol decline was, however, marginally significant ($p < 0.10$) suggesting that employees, who slept longer during the night, had a steeper cortisol decline during the following work day resembling findings from some previous studies (Kumari et al., 2009; Minkel et al., 2014).

One potential explanation for not detecting a relationship between daily sleep and afternoon blood pressure could relate to the stability of blood pressure over time. Guidelines specify that an ICC of 0.40 to 0.80 indicates substantial variance on the day level to necessitate a multilevel approach (Cicchetti, 1994; Koo & Li, 2016). In the present study, a large amount of variance in blood pressure (69%) was between individuals. Even though there seems to be sufficient variance at the day level, it could be more difficult to detect smaller effects, thereby explaining our non-significant results. A more theoretical explanation may relate to the notion that sleep is a primary outcome in the stress process leading to more serious secondary outcomes, like increased resting blood pressure, over a longer time (Ganster & Rosen, 2013). Therefore a 6-week period may be too short to show the effects of sleep on resting blood pressure.

Besides the use of momentary stress measure discussed above, another reason for not detecting a relationship between daily sleep and subjective stress is that daily vigour in terms of mobilizing daily energy plays an important role in the day-level relationship. Indeed, it appeared that daily sleep quality and quantity were related to subsequent experience of stress through morning vigour—suggesting that mobilisation of energy seems to be important for how employees deal with stress. Our findings are in line with the COR theory (Hobfoll, 1998; Hobfoll & Shirom, 2001), indicating chains of resource gains and losses. Accordingly, poor sleep in terms of quality and quantity relates to lower vigour. Thus a bad night's sleep does not replenish depleted energy resources, which may relate to higher stress in the afternoon. Our findings regarding the day-level relationship between poor sleep and low vigour, as well as the relationship between low vigour and subjective stress, are also in line with previous studies (Barber et al., 2013; Clinton et al., 2017; Kühnel et al., 2017; Schmitt et al., 2017; Sonnentag, Mojza et al., 2008).

However, vigour did not function as a mediator in the daily sleep-physiological stress relationship, as morning vigour was not related to physiological stress markers. Although this relationship is theoretically sound, its empirical evidence is minor, contradictionary, and mostly related to studies on work engagement (e.g., Black et al., 2017; Langelaan et al., 2006). Altogether, our study did not show significant relationships between physiological stress and subjective experiences of vigour, but the relationship between subjective stress and blood pressure was significant. This latter relationship may relate to the fact that they both were measured at the same time in the afternoon, giving support to the view that stress can temporarily increase blood pressure. Finding only few relationships between subjective and physiological indicators is perhaps not a surprise, as, for example, Liu et al. (2021) concluded on the basis of their study that self-reported stress and physiological indexes of arousal are relatively distinct components of the individual stress experience (see also Brown et al., 2020).

One methodological explanation for not finding the associations between subjective indicators and physiological stress relates to the timing of these measures. We measured vigour in the morning retrospectively, subjective stress and blood pressure in the afternoon, and cortisol decline was based on morning peak and evening measures. Thus the time lags between the measures vary which may weaken the possibility to find associations between them. Nevertheless, our main aim was to examine lagged, not simultaneous, effects. Future studies should continue to examine whether subjective and physiological daily stress markers, measured in field studies, are in fact correlated, and what factors play into this relationship.

6.2 | Strengths, limitations and suggestions for future research

The present study has several strengths. First, the experience sampling design enables us to draw conclusions about short-term daily fluctuations of sleep and stress. Second, focussing on potential underlying mechanisms of the sleep-stress relationship (i.e., daily vigour) contributes to in-depth understanding of the sleep-stress relationship. Third, we took both sleep quality and quantity into account and did not only assess subjective stress, but complemented this measurement by including physiological stress measures reflecting HPA-axis and SAM-system activation. In future studies other mediators of the sleep-stress relationship would be worth studying.

Next to these strengths, our study has limitations that should be considered when drawing conclusions about the results. First, the specific group of employees that participated in this study may limit the generalisability of the results to the general population. Participants were predominantly female, highly educated, mainly worked in knowledge-intensive jobs, and were rather healthy. These factors may also play a role in the relationships we found. For example, in an unhealthier sample a higher stress level would be likely, which may also be reflected in physiological stress markers. Also, the low response rate may have effects on the generalisability of our results. For example, it is possible that those who did not take part in our study felt that the study was too demanding with all the measurements required, signalling higher stress, which may have reflected in our results. Replicating our results within more diverse samples in terms of gender, education, type of job, and health would strengthen the conclusions.

A second limitation is our use of several single-item measures (i.e., to assess daily sleep quality and quantity, subjective stress, and vigour). Use of one-item measures may have reduced construct validity of our measurement instruments and may limit robustness of our results. However, since we asked participants to also provide daily blood pressure measurements and salivary cortisol several times a day, it was in practice impossible to use longer scales to measure the concepts. In fact, it has been shown that single-items measures can be valid and realible and used in certain circumstances (see Elo et al., 2003; Fisher et al., 2016; Hahn et al., 2011). Concerning our one-item measure of vigour, it was not the one item selected for the ultra-short work engagement scale invented after our study was conducted (Schaufeli, 2018). Therefore, this item may have not been the best choice. In the occupational context, vigour is, however, closely related to motivational processes, as work motivation is often viewed as a set of energetic forces that originate within individuals and that determine the form, direction, and intensity of work-related behaviour (Shirom, 2010). Thus, vigour can be regarded a precursor of motivation at work. This view supports our item choice. In different research designs with fewer measurements within-persons, longer scales could be used to assess core constructs. We recommend that future studies solely focussing on disentangling the sleep-stress relationship should also include longer measures of daily sleep quality and use sleep actigraphy to assess objective sleep parameters (e.g., sleep duration).

Third, as we used retrospective evaluations for measuring morning vigour, our results concerning the mediator results may have been partially biased by experiences that participants had later that day. However, the stress outcomes were based on afternoon SMS-questionnaires, afternoon blood pressure measurements, and morning and evening saliva samples, which were measured independently from morning sleep and vigour.

Fourth, our study showed that it is very challenging to conduct physiological measurements in the field. There are multiple confounders which may impact cortisol or blood pressure measurements (e.g., drinking alcohol, snoozing before getting up in the morning). We asked participants to avoid certain behaviours 30 min before each data collection, and to respond to a short survey on their behaviours after each physiological measurement. However, conducting studies in the field settings will always result in confounders that cannot be fully taken into account. Furthermore, we were very careful in cleaning and preparing the data for the analyses. Concerning cortisol measurements, it is possible that the peak of cortisol excretion was not reached after 30 min since wakeup. When measuring cortisol awakening response, the full procedure includes also a measurement after 45 min since wakeup. Due to too much burden for the participants, we had to omit this measurement. This shorter procedure is also used in research, but it may have had an effect on CDD values, which describe a decline over the remainder of the day after the peak. The so-called CAR non-responders would also need further research attention to find out to which extent the issue relates to non-adherence to the protocol of collecting saliva samples and to which extent to other factors and 'true' physiological differences. Despite the challenges, we consider it worthwhile to look deeper into the within-person associations between physiological and self-reported stress.

6.3 | Practical implications

Our study has implications for practitioners, employers, supervisors, and employees. Daily sleep quality and quantity were closely related to vigour—being enthusiastic about going to work in the morning—and subsequent experiences of stress. Thus, employers and supervisors may advise their employees on improving sleep hygiene to promote daily energy and stress levels. Maintaining a consistent sleep-wake schedule, limiting caffeine intake, and regular exercise are only a few suggestions how employees could improve their sleep quality and increase sleep quantity. Supervisors showing supportive leadership behaviours directed to improve employees' sleep and promote balance between work and non-work life has been shown to lessen employees' self-rated sleep disturbance and sleep impairment (Sianoja et al., 2020). Thus supervisors are encouraged to show positive interest towards employees' healthy sleeping habits and plan work accordingly. The impact of supervisors and work arrangements on sleep in shift work is obvious but even for those working in regular day jobs organisations and supervisors can support sleep. Such practices could include providing flexible working time, avoiding scheduling work tasks early in the morning or very late in the afternoon, and finding flexible solutions to balance work and family demands so that employees have more time to sleep during nights. Another important suggestion in today's digital society is to limit technological connectivity to work as staying connected to work during nonwork time undermines processes that are important for recovery, mainly psychological detachment from work and sleep (Sonnentag, 2018). Employers and supervisors could try to support employees in this effort by clearly communicating that employees are not expected to reply to emails in the evening after work. Supervisors should also refrain from contacting employees outside working hours.

Our results highlight that daily vigour and energy may determine whether poor sleep results in increased feelings of stress during the day. Thus, another implication is to find ways of improving an employee's daily vigour. One way to improve vigour is by increasing job resources at different levels (organisation, leader, group). Nevertheless, organisational-level resources (reflecting how the work is organized, designed and managed) contributed more strongly to work engagement than group-level (interpersonal relationships), and leader-level resources (leadership characteristics) in a meta-analysis by Lesener et al. (2020). Examples of organisational-level resources are skill discretion, role clarity, and opportunities for development. These all are also resources contributing to vigour by promoting motivational processes at work (Shirom, 2010).

7 | CONCLUSION

The present diary study showed that sleep quality and quantity were related to afternoon subjective stress through morning vigour, indicating that daily energy and enthusiasm regarding work are important for employees to experience less subjective stress. In addition, our study points to the difficulty of assessing subjectively perceived vigour or stress with physiological measures in a field study. New technology and more precise ways to assess stress physiology in a field setting without intruding and disrupting people's daily life may guide future research on sleep and its daily consequences for employees.

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CONFLICT OF INTEREST

We have no known conflict of interest to disclose.

DATA AVAILABILITY STATEMENT

The data are available on request from the first author. The data are not publicly available due to privacy or ethical restrictions.

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