Investigating Factors on Restorative Sleep Quality and its Relationship with Personal Work Performance - An Analysis of Diary Data

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1 Introduction

Sleep supports various functions of the human body such as the optimization of memory contents in the human brain, repair and restorative processes [1], and is a crucial aspect for the well-being of an individual [2]. Therefore, sleep is one of the most important processes for human functioning and the process of learning and memorizing various information that are assumed to be of importance for work performance [1]. One research study shows that poor sleep quality can lead to increased work impairment and can even affect concentration and organizational skills [3], which illustrates the cruciality of investigating factors that influence the sleep quality of individuals and its connection with work performance. Furthermore, the amount and quality of sleep are associated with physical and mental health problems [4]. Another study executed a systematic review of longitudinal and intervention research in this context in order to reveal the relationship between sleep quality and psychosocial work characteristics [5]. The results suggest that these characteristics influence the sleep quality, however, they did not find enough studies to conclude that the reversed statement holds even though highly possible. The authors further conclude that it is important to find the root causes and mechanisms that lead to poor sleep quality. In other large cross-sectional studies, however, sleep quality has been found to impact work performance [6]. The hyperarousal model of insomnia is a well-established framework to identify risk factors for impaired sleep [7]. As part of the model, the concept of sleep effort gained increased attention [7]. A core assumption of the model is that insomnia results from an over activation of bodily systems, especially the brain. Therefore, workplace factors are of interest that might either increase activation or enable deactivation. Among those factors, work related rumination has been found to increase cognitive activation and impact sleep negatively while positive work reflection and recreational activities might lead to deactivation [8]. However, so far, these factors were investigated separately which makes it hard to determine their unique and incremental impact on sleep. Since impaired sleep is widespread in the general population and can lead to reduced work productivity, work disability, accidents, educational and social disadvantages, and

substantial costs for both individuals and society [5, 9], the analysis of such factors is crucial.

Data in this context such as the sleep quality and other psychological factors are often collected in Internet-based interventions by taking advantage of Ecological Momentary Assessments (EMA). Internet-based treatments can lead to comparable outcomes as treatment as usual and have also demonstrated to be cost-effective [10]. In general, interventions that are delivered on the Internet have been shown to contribute to the improvement of insomnia and the overall sleep of individuals and recent studies provide further evidence of the effectiveness of Internet-based interventions in the context of cognitive behavioral therapy for insomnia [11, 12]. They can offer high quality treatment and simultaneously provide insight into the daily lives of participants [13]. EMA methods for data collection enable researchers to record a variety of factors and most importantly close in time to the participants' experience and in their natural environment [14]. Since diaries, one form of EMA methods, can be collected through electronic devices due to the technological development, greater ecological validity can be achieved [14]. At the same time, deeper insight about the participants and their natural behavior can be recorded, even though of a subjective nature, which in turn can result in an increased understanding of participants' behavior and relationships between factors that can potentially enhance the overall treatment outcome.

In this paper, we seek to analyze the relationship between various self-reported and sleep-related psychological factors and restorative sleep quality from now on referred to as sleep quality. For our approach, we utilized diary data that was gathered in an online-based intervention with the majority being teachers affected by insomnia [15]. Specifically, we examine the effects of work related rumination, positive work reflection, recreational activities, and sleep effort on the sleep quality and subsequently its impact on the individual performance level. At the same time, we demonstrate how to analyze diary data in this context by using Bayesian estimation techniques. We utilize a modified and thus individualized ordered logit model and Markov Chain Monte Carlo (MCMC) techniques for parameter estimation. Despite extensive research on sleep quality and cognitive performance such as the work of [16] or [17], surprisingly little is known about the influences of the mentioned predictors on the sleep quality and the relationship between sleep quality and personal performance; especially among teachers. To the best of our knowledge, we are the first to develop a model including all of the mentioned types of predictors in the same pool of participants, include client individual parameters in order to account for heterogeneity among the participants, and analyze the connections using Bayesian estimation techniques. By doing so, the contribution of this article is twofold. We contribute to existing research by illustrating a path for the analysis of diary data in Internet-based interventions in an individualized fashion and by revealing the relationships between a multitude of psychological factors.

2 Materials and Methods

2.1 Data

The data for this research was initially gathered in four studies that evaluated "the efficacy of a guided Internet-based recovery training for employees who suffer from both work-related strain and sleep problems" [15]. Recruiting the participants by email, our dataset represents responses of employed persons who are 18 years or older, have symptoms of clinical insomnia, and exhibit no signs of suicidal behavior. The dataset consists of a large group of primary, secondary, and vocational school teachers (343) because two of the four studies were addressed solely to teachers [15].

Furthermore, the participants completed a sleep/regeneration diary. Our analysis is based on this data. Here, the clients can score on a ten-point scale if they encounter difficulty disengaging from the job after a day's work (1 = completely wrong; 10 = completely true), how many activities they have conducted in regard to recovery (1 = no activities; 10 = a lot of activities), how restorative they have perceived their sleep (1 = not restorative at all; 10 = completely restorative), and how well they have performed compared to their best performance ever (1 = completely unproductive; 10 = highly productive/best productivity). The variable positive work reflection was measured by a four-point scale (yes, rather yes, rather no, no). The participants can score if they have been thinking about the positive aspects regarding their work after the end of a work day. Sleep effort was assessed by a binary response. Participants can state "yes" or "no" if they struggled to fall asleep. The data is provided once a day. As shown in Figure 1, observations are repeated for each participant and psychological concept t times; the average of observations for one client is 32. In total, the analyzed dataset includes 432 individuals and 13,984 observations. Based on these measurements, the dependent variables, defined as the sleep quality and the performance level, are predicted.

In the following, we illustrate the psychological factors used as predictors from the ten-item diary in more detail and introduce the dependent variables and our hypotheses.

Figure 1. Data collection process; t repeated observations for each client n and psychological concept including predictions based on collected diary data.

2.2 Psychological Factors and Approach

Mental detachment from work (MDFW) | MDFW means completely eliminating any thought regarding work, switching off, and disconnecting from both the positive and negative work processes [18]. Teachers often report immense rumination [19] but even after leaving the workplace, almost every individual occasionally ruminates about work [20]. The challenge of proper mental detachment from work in today's generation due to an increased converge of leisure time and work is just one reason for a growing demand of knowledge regarding how work habits affect the quality of an individual's sleep and subsequently how the performance level is influenced [3].

Sleep Effort (SE) | SE, possibly an important factor for insomnia [21], can be defined as the struggle to fall asleep or "the attempt to force and induce sleep in a voluntary manner" [22]. Sleep effort can represent an important factor for sleep quality because strenuous efforts to fall asleep can lead to disturbances at night and sleep problems. Individuals who suffer from poor sleep quality often also report high sleep effort and problems at work and in their personal lives [2].

Positive Work Reflection (PWR) | Employees often take home work related thoughts and it is intuitive that job dissatisfaction in general can potentially lead to a higher risk of insomnia and bad sleep quality [7]. However, thinking about work is not necessarily linked to negative thoughts [19]. Thinking and reflecting about work situations can possibly help individuals to cope with certain stress situations and evaluate their actions and behavior. Therefore, also "good" feelings about work can influence individuals [23]. Positive work reflection has been shown to help decrease a persons' stress level while the nonexistence of it can result in poor general well-being [17]. However, little

is known about the effects of positive feelings about the job after a successful day at work on the sleep quality of individuals.

Recreational Activities (RA) | In general, RA seek to adjust and repair the negative effects an individual suffers from due to exertion or strain [24] and sidetrack from work related thoughts [15]. While work and sleep take up a large amount of a person's daily activities, other activities are necessary to cope with stress and daily situations. Thus, how an individual spends leisure time is important for the recovery process [19]. Additionally, recreational activities can potentially increase life satisfaction and simultaneously influence the sleep quality in a positive way by distracting from work [25].

Sleep and Performance | Sleep can be measured by quality and quantity. Sleep quantity is an objective measure that specifies the time someone is asleep. Sleep quality indicates a more subjective experience of an individual. The extent of satisfaction of sleep and overall feeling of being well-rested after waking up play a major role regarding the sleep quality [16]. Poor sleep quality is associated and correlated "with increased physical health complaints and with increased feelings of tension, depression, anger, fatigue, and confusion" [16]. Research further indicates that individuals who have poor sleep quality often remain in lower pay grades, achieve worse grades, and are less likely to obtain higher degrees such as doctorates [26,27]. Because sleep quality evidently has tremendous effects on the well-being of an individual and evidence is growing that it is also better related to health problems than sleep quantity, we focus on sleep quality in our analysis [16]; being interested in how the sleep quality is affected by the previously introduced psychological factors and how it subsequently influences the performance level of individuals.

Approach and Hypotheses | Figure 2 illustrates the relationships to be analyzed. Based on the mentioned existing literature, we hypothesize positive effects from the variables recreational activities, positive work reflection, and sleep quality. We further assume negative effects from the variables mental detachment from work and sleep effort.

Figure 2. Relationships of psychological factors to be analyzed in this study.

2.3 Statistical Method

The dependent variables in our analysis are the quality of sleep and the performance level of the clients. Both factors, sleep quality and performance level, are simultaneously estimated. Specifically, sleep quality is a dependent and independent variable at the same time. The dependent variables use an ordinal scale. Although the scores on the scale are ranked, the "real" space between the ranks remains unknown [28]. For data analysis and especially diary data analysis, regression and multilevel analyses (i.e. hierarchical linear models) are frequently used in research [29]. These methods are beneficial especially when seeking to reveal variances between the different hierarchies (between-group and within-group variance) [30]. However, we utilize an ordered logit model and employ Bayesian MCMC techniques for estimating the parameters, which enables us to incorporate prior knowledge and combine this information with the data provided by the participants. Furthermore, an ordered logit model can reveal the real space between the ranks and simultaneously evaluate relationships and influences between predictors and dependent variables.

However, the ordered logit model makes an important assumption - the proportional odds assumption. It assumes that the relationship between the independent variables and the outcome for the dependent variable (sleep quality/performance) do not depend on the rank [31,32]. This assumption is often violated in real-world datasets [33]. Thus, as suggested by [34], we perform likelihood ratio tests of the proportional odds assumption by utilizing the 'ordinal' package [35] in R [36]. This test is found to be significant for the variables mental detachment from work ($2.2 \cdot 10^{-16}$), sleep effort ($2.6 \cdot 10^{-5}$), recreational activities ($2.2 \cdot 10^{-16}$), and sleep quality ($7.2 \cdot 10^{-8}$). The variable positive work reflection is insignificant (0.3571). These results indicate a violation of the proportional odds assumption for all variables except positive work reflection. Therefore, we utilize a generalized ordered logit model for our approach [32,37]:

$$\ln(\theta_{ijt}) = \alpha_{ij} - (X_{jt}\beta_{ij}),$$

where i stands for a specific rank of the scale, j for each individual, and t for the response of an individual at different times. The term $\ln(\theta_{ijt})$ is a logit. It is the log of the odds that a specific event occurs for every individual j where $\theta_{ijt} = \frac{P(rank \leq i | x_{jt})}{P(rank > i | x_{jt})}$.

Specifically, the probability of being ranked as one (given x for a specific client j at time t) is put into relation to being ranked as two or higher. Afterwards, the probability of being ranked as one or two is compared to being ranked as three or higher et cetera. The term α_{ij} , where $i = 1, \dots, rank - 1$, represents a cut-off for the boundaries of the categories. Usually, it varies throughout the logits since every category possesses its own α - term. X_{jt} stands for the independent variables for participant j at time t and β_{ij} are the parameters to be estimated. The index i in the β - terms indicates the generalized ordered logit model since each parameter can now vary amongst the ranks.

We compare two versions of the generalized ordered logit model. We estimate the original model without accounting for heterogeneity among the clients and include two

different types of heterogeneity. One type of heterogeneity is already mentioned by [38] and [39]. They discuss the problem that individuals can perceive boundaries between the categories in different ways and develop varying response patterns. This can, for example, result in rather using the bottom or middle part of the response scale. Not taking the so called "scale usage heterogeneity" into account can potentially bias analyses essentially [40]. We seek to address this varying behavior of clients regarding scales by modifying the model and implementing user specific heterogeneous thresholds. Hence, we implement client specific cut-offs for every individual j into α . Furthermore, we take advantage of MCMC methods which allows us to account for another type of heterogeneity amongst the participants. We implement a client specific β - parameter value. This value defines the impact each item has on an individual j and therefore varies amongst the participants.

Figure 3. Plate notation of hierarchical structure of the model.

Figure 3, a plate notation, illustrates the hierarchical structure of the model. In general, α and β are sampled from a normal distribution with high variance. Based on current literature already mentioned above and our assumptions, we implement specific priors for the predictors. We set a weak negative prior for the variables sleep effort and mental detachment from work. Moreover, we implement a weak positive prior for the variables recreational activities and sleep quality. By doing so, we consider knowledge from related literature and incorporate our assumptions. Concurrently, we only implement weak priors in order to not create influences of a strong nature. Particularly, we let the likelihood dominate the posterior distribution. We also implement an uninformative prior for the variable positive work reflection because we do not have deep beliefs on how this variable could influence the sleep quality and, as mentioned above, little is known in the literature about its influences on the sleep quality.

The rank and user specific individual parameter values (α_{ij} , β_{ij}) are also sampled from a normal distribution with high variance. The logits for every client j and every response in time t are calculated and then transferred into a probability. Thereupon, Y , a specific outcome for the dependent variable (sleep quality/performance), is sampled from a categorical distribution based on the individual probabilities. The model is

realized in R [36] and we utilize JAGS (Just Another Gibbs Sampler) for MCMC sampling [41]. We run three parallel MCMC chains, each 10,000 iterations, and store every twentieth draw from the last 5,000 iterations.

3 Results

For demonstrating the importance of accounting for heterogeneity, we provide a comparison of the generalized ordered logit model without any heterogeneity terms and the above specified model. We compare the models by the Deviance Information Criterion (DIC) [42]. Since the DIC is especially appropriate for Bayesian models and it does not require additional Monte Carlo sampling, we utilize this measure for comparison. The values illustrate a more adequate performance, the smaller the DIC value. As expected, we found that the DIC of the generalized ordered logit model that includes heterogeneity amongst the participants (95,012.8) is tremendously smaller than the value for the model without the heterogeneity terms (108,875.7). This indicates a superior performance.

Table 1. Results for the effects on sleep quality and performance – estimated model parameters including High Density Interval.

<i>Variables</i>	<i>50%</i>	<i>2.5% HDI</i>	<i>97.5% HDI</i>
MDFW	-2.57	-2.94	-2.21
SE	-4.32	-4.72	-3.90
PWR	0.51	0.12	0.85
RA	1.05	0.67	1.41
Sleep Quality	0.42	0.09	0.75

Further, we summarize the estimation of the parameters and computation of the mean and quantiles of the distribution in Table 1. As illustrated, mental detachment from work influenced the sleep quality in a negative way. Our analysis also indicates that if an individual struggles to fall asleep, the sleep quality was significantly affected in a negative way as well. As hypothesized, we also found that positive work reflection affects the sleep quality slightly positively. Table 1 further illustrates that recreational activities had a positive influence on the sleep quality. A positive coefficient means that a higher value for the corresponding variable increases the likelihood of a reported good sleep quality. As we can see, mental detachment from work and sleep effort influenced the sleep quality to a greater extent compared to positive work reflection and recreational activities.

The results also indicate that the sleep quality slightly affected the personal performance level significantly in a positive way. Our finding is consistent with

previous research, for example with that of [43], who also find that sleep quality is related to academic performance of students. All results are significant and we can confirm our hypotheses.

4 Discussion

With this paper, we seek to demonstrate how different psychological factors influence the sleep quality and how the sleep quality itself affects the performance level of individuals based on diary data from an online-based intervention. For this purpose, we utilize an individualized and generalized ordered logit model in a Bayesian context. Our approach demonstrates how data from online-based interventions, in this case diary data, can be analyzed. Data gathered in these Internet-based interventions furthermore enable researchers and practitioners to develop a deeper understanding of fundamental relationships between psychological factors. Therefore, understanding participants and gaining insight into the effects of important psychological items is a crucial factor for online-based therapy.

The demonstrated results indicate how statistical analyses can benefit from client-specific parameters. Therefore, we demonstrate the importance of heterogeneity amongst participants by considering varying influences of factors and simultaneously allowing for a higher degree of freedom in the model. This can potentially improve the performance of statistical analyses in this context. Expecting every client to react and behave the same way in individual situations appears to be unrealistic because humans behave and are affected by certain situations differently.

Our findings further illustrate that focusing on improving problems in regard to rumination about work and how to handle the struggle of falling asleep can potentially improve the client's sleep quality since these variables showed negative effects on the sleep quality. Consistent with the findings of [44], rumination about work is a significant factor for restorative sleep. As noted by [44], no detachment from work decreases recovery and therefore can lead to fatigue. Another reason for this effect to occur, especially when working from home, might be the distraction from leisure time and the subsequent "force" for individuals to always be on the job. Of course, thinking about the job can also help reflect about critical situations at work; always being preoccupied with work related thoughts, however, might have negative effects on the individual. As already stated by [21], sleep effort might be one factor for insomnia. We find a strong negative effect created by a struggle to fall asleep on the sleep quality. This can possibly be due to the fact that high sleep effort can lead to a greater level of stress [45] and subsequently to lower sleep quality. More research is necessary in order to confirm this hypothesis. Moreover, according to our results, positive work reflection benefits the sleep quality of individuals slightly. As noted by another study, positive work reflection might reduce burnout and increase well-being [17]. We hypothesize that this fact and positive work reflection in general – thinking about the positive aspects of the job - can lead to the feeling of satisfaction and helps individuals to switch off and fall asleep. Recreational activities, which are found to have a positive effect on the sleep quality as well, can possibly release stress, distract from work stress [15, 25]

and potentially free one's head. We expected this positive influence of recreational activities and the results are consistent with our hypotheses. However, we expected the positive effect of this predictor to be stronger. Supporting participants in actively recognizing positive outcomes of their professional work life, concentrating on those positive outcomes, and further recommending physical and social recreational activities can possibly lead to "better" sleep quality.

Like previous research, we find a relationship between sleep quality and the personal performance of individuals. More sufficient sleep quality can therefore lead to a greater individual performance level. A likely reason for the existing relationship between sleep quality and the performance level can be that poor sleep quality and disruption of sleep can potentially reduce the overnight brain activity, which leads to decreased neurocognitive functioning including reduced creativity, the ability to perform complex tasks, and abstract thinking [46,47].

Besides the results and implications our analysis provides, we also outline some limitations regarding our research. The utilized dependent variables were assessed only by one question. Sleep quality and work performance are complex factors that are often measured using more structured questionnaires such as the Pittsburgh Sleep Quality Index. Using only one question for this assessment might not represent the whole complexity of the dependent variables even though this question is related to an item of the Consensus Sleep Diary [48], which assesses sleep quality. Furthermore, although our analyzed dataset is comparatively large, we only possess self-reported and optional data from clients. Self-reported data represents a good tool for analyzing the feelings and behavior of therapy participants. However, developing more accurate and objective "psychological and biological" measures can further enhance analyses and may make results more representative [19]. Additionally, only one touchpoint exists for every participant each day. More frequent measures can potentially lead to more detailed datasets and therefore to deeper and more accurate analyses. The first step for achieving this is to make the diary a mandatory tool in the therapy process and perhaps oblige the participants to complete the questionnaire multiple times a day. Especially in analyses that seek to analyze influences of different types of predictors, more data often offers great potential for more precise conclusions. Another important aspect to mention is that our data consists of a large group of school teachers and different amounts of male (27%) and female (73%) persons. These facts might limit the statement and representativity of our results.

Since we only obtain data from Germany, it can also be interesting to analyze datasets that include participants from various countries. This can possibly generalize the findings and lend analyses more international significance. However, data from multiple countries, especially when surveys and questionnaires are involved, can also indicate problems concerning great differences in scale usage between the countries [40] and further lead to data privacy issues. Despite privacy concerns, a possible solution in regard to scale usage differences can be an implementation of country specific priors into the model in order to consider differences in behavior due to the home country.

Evidently, further room for improvement and more analyses exists. Implementing other factors such as the stress level of participants, dropout information, or the sleep

quantity into our model can potentially enhance our analysis and provide deeper insight and therapy implications. However, not only the sleep quality or the performance level seem to be an important issue regarding mental health problems. Analyzing effects on the mood level of individual participants, especially considering different types of activities and their relationships, can also be of great interest. We seek to leave these questions open for further research.

In conclusion, we have illustrated a path of how to analyze diary data of online-based interventions by considering individual behavior of clients. Simultaneously, we analyzed the relationships between a multitude of psychological factors and found that self-reported sleep quality is affected negatively by not being able to detach from work and high sleep effort. On the other hand, positive work reflection and recreational activities have a positive influence on the sleep quality. The results further demonstrate that good sleep quality can affect personal work performance positively. We hope we can remind the society of the importance of sleep quality, its predictors, the effects it evidently has on the individual performance level, and the value of data that is collected in online-based interventions.

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