Strengths of associations between depressive symptoms and loneliness, perfectionistic concerns, risky alcohol use and physical activity across levels of sleep quality in Swedish university students: A cross-sectional study

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Summary

Previous research shows that sleep quality may interact with some other predictors of depression, such that poor sleep could strengthen the association between these factors and depression. We aimed to determine the presence of statistical interactions between sleep quality and loneliness, risky alcohol use, perfectionistic concerns and/or physical inactivity in relation to depressive symptoms. Further, we aimed to describe the functional form of the statistical interactions and associations. We used a cross-sectional design and included 4262 Swedish university students. All measures were self-reported, sleep quality was measured with the Pittsburgh Sleep Quality Index, and depressive symptoms with the short-form Depression, Anxiety and Stress Scale. Regression models of increasing complexity (linear and non-linear, with and without interactions) were compared to determine the presence of associations and statistical interactions, and to explore the best functional form for these associations and interactions. Out-of-sample R² from repeated cross-validation was used to select the final models. We found that sleep quality was associated with depressive symptoms in all final models. Sleep quality showed a linear interaction with perfectionistic concerns in relation to depressive symptoms, such that perfectionistic concerns were more strongly associated with depressive symptoms when sleep quality was poor. Loneliness, risky alcohol use and physical inactivity were non-linearly associated with depressive symptoms but did not interact with sleep quality. We concluded that out of the four examined variables, only perfectionistic concerns interacted with sleep quality in relation to depressive symptoms. This interaction was weak and explained little of the overall variance in depressive symptoms.

KEYWORDS

alcohol use, depression, interaction, loneliness, perfectionism, sleep quality
1 | INTRODUCTION

Sleep disturbances are a common and increasing problem among university students. A recent study found that up to a third of students met criteria for insomnia in 2018 compared with 23% in 2010 (Sivertsen et al., 2019). This trend is highly troublesome in terms of students’ mental health, as sleep disturbances have been identified as a risk factor for depression as well as other psychiatric disorders (Baglioni et al., 2011; Hertenstein et al., 2019). Depression is a major public health concern, ranking as one of the leading causes of disability worldwide (James et al., 2018), and university students are particularly affected, with a higher prevalence of depression than the general population (Ibrahim, Kelly, Adams, & Glazebrook, 2013; Rotenstein et al., 2016).

Besides sleep disturbances, there is a range of other risk factors for depression (Kendler, 2014). From biological risk factors such as genes, to psychosocial, psychological and behavioural factors. Earlier research has suggested that the associations between several such factors and depression may vary in strength depending on the level of sleep quality, i.e. that there are interactions between sleep quality and other factors in relation to depressive symptoms. Longitudinally, sleep disturbances have been shown to strengthen the association between psychosocial stressors such as negative life events (Leggett, Burgard, & Zivin, 2016), high job stress (Magnusson Hanson, Peristera, Chungham, & Westerlund, 2017) and parenting stress (da Estrela, Barker, Lantagne, & Gouin, 2018) and depression and mood. Cross-sectional studies suggest that poor sleep quality strengthens the associations between depressive symptoms and psychosocial factors such as social isolation (Richardson et al., 2019) and chronic medical conditions (Jang, Shin, Cho, Kim, & Chiriboga, 2011), as well as the association between behavioural factors such as physical activity and internalizing problems (Gillis & El-Sheikh, 2019).

However, evidence on how sleep quality interacts with other factors related to depression is still limited. It has been suggested that poor sleep can disturb emotion regulation (Palmer & Alfano, 2017), which is a potential mechanism by which sleep disturbances could increase the vulnerability to other risk factors for depression. An increased understanding can further deepen our knowledge of the development of depression and point to important targets for prevention and treatment. If the effects of other risk factors on depression depend on sleep quality, improving sleep quality could potentially increase the resilience to other risk factors for depression.

In this study, we investigate whether risky alcohol use, physical inactivity, loneliness and perfectionistic concerns interact with sleep quality in relation to depressive symptoms cross-sectionally. We aimed to study a range of factors including behavioural (physical inactivity and risky alcohol use); psychological (perfectionism) and psychosocial (loneliness) factors. All these variables have been suggested as risk factors for depression, both in the general populations and in students (Boden & Fergusson, 2011; Erzen & Çikrikci, 2018; Mammen & Faulkner, 2013; Sheldon et al., 2021; Smith et al., 2016). Although these four variables are by no means exhaustive of the large set of potential risk factors for depression, they represent different levels of risk factors (behavioural, psychological and psychosocial) whose impact on depressive symptoms could be affected by sleep quality.

It has been noted that complex systems, such as that of depression and its correlates, are likely to include non-linear interactions (Kendler, 2008). Non-linear interactions could occur, for instance, if the negative effect of a risk factor on depression is amplified by poor sleep quality, but only once sleep quality is above a certain threshold level (Figure 1, right panel). Alternatively, it could occur if the negative effects of a risk factor increase exponentially as sleep quality worsens (Figure 1, middle panel).

A limitation of most previous research on sleep quality and depression is the use of statistical methods that are unable to represent non-linear effects. This may lead to misrepresentations or failure to detect non-linear associations and interactions (Belzak & Bauer, 2019). A recent exception was a study by El-Sheik et al. (El-Sheikh, Philbrook, Kelly, Hinnant, & Buckhalt, 2019) showing that children’s subjective sleep quality was negatively associated with parent-rated internalizing symptoms, but only when levels of sleep quality were worse than moderate, and that this association differed depending on ethnicity (i.e. interacted with ethnicity). Examinations of non-linear associations and interactions can provide clinically useful knowledge regarding at what levels (threshold effects), and under what circumstances (interaction effects), poor sleep quality may interfere with mental health.

Given the sparsity of studies, we believe there is a need to investigate how sleep quality interacts with other factors at different levels (behavioural, psychological and psychosocial) in relation to depressive symptoms while allowing for non-linearities.

The first aim of this study was to determine whether sleep quality statistically interacts cross-sectionally with loneliness, risky alcohol use, perfectionistic concerns and/or physical inactivity in relation to depressive symptoms in Swedish university students. Secondly, we aimed to explore different functional forms to determine which best describes these potential associations and interactions.

2 | PARTICIPANTS AND METHODS

2.1 | Participants

We used data from the baseline assessment of the Sustainable University Life cohort (http://clinicaltrials.gov/ ID: NCT04465435). Eligible participants were full-time students with at least 1 year left of their education, recruited from eight universities in the greater Stockholm area and Örebro during 2019 and 2020. The targeted universities were a convenience sample aiming to represent a variety of university programs.

2.2 | Data collection

Students at the targeted universities received email invitations to participate in the study with a link to the web-survey. Study
representatives presented the study to the invited students in-class (digitally or at campus) at all but one university, where the in-class presentations were deemed logistically unmanageable. Information about the study was also spread through relevant social media (e.g. student union channels), and at campus noticeboards and campus information sites. The study was approved by the Swedish Ethical Review Authority (reference number: 2019-03276, 202001449). Informed consent was provided by all participants electronically prior to completing the baseline survey.

2.3 | Measurements

Depressive symptoms were measured using the depression subscale of the short form Depression, Anxiety and Stress Scale (DASS-21; Henry & Crawford, 2005). The depression subscale consists of seven items rated 0 (Did not apply to me at all) to 3 (Applied to me very much, or most of the time), with a recall time of 1 week. The items are summed to give a subscale-score ranging from 0 to 21. The DASS-21 has shown good validity among Swedish university students (Alfonsson, Wallin, & Maath, 2017). Cronbach’s $\alpha$ in this sample was 0.91.

Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds 3rd, Monk, Berman, & Kupfer, 1989). The PSQI is a self-rated measure of sleep quality comprised of 19 items, of which 15 are rated on a scale 0–3, and four are open-ended and recoded to a scale 0–3. The recall time is 30 days. These items are converted to seven different domains, each scored 0–3, representing different aspects of sleep. Summing all domain scores gives a global score ranging from 0 to 21, which was used as a measure of overall sleep quality, with higher scores indicating worse sleep quality. The PSQI has shown good validity and reliability for measuring sleep quality in university students (Liu, Kahathuduwa, & Vazsonyi, 2021). Cronbach’s $\alpha$ in this sample was 0.74.

Perfectionistic concerns were measured using the Frost Multidimensional Perfectionism Scale (Frost, Marten, Lahart, & Rosenblate, 1990) subscale Concerns over Mistakes (FMPS-CM). The FMPS-CM subscale consists of nine items. The items are originally rated on a five-point scale from 1 (Strongly Agree) to 5 (Strongly Disagree). The rating scale used in this study was a six-point scale from 0 (Strongly Agree) to 5 (Strongly Disagree). The items are summed to give the subscale score. Cronbach’s $\alpha$ for FMPS-CM was 0.91 in this sample.

Weekly physical activity was measured using two items (Socialstyrelsen, 2011). The first item assessed weekly minutes of physical exercise (such as aerobic exercise), and the second item assessed weekly minutes of physical activity in daily activities (such as walking and cycling). Minutes of physical exercise was multiplied by two to account for intensity and added to minutes of physical activity in daily activities to create a measure of minutes of weekly physical activity.

Loneliness was measured using the UCLA three-item loneliness scale (UCLA-lon; Hughes, Waite, Hawkley, & Cacioppo, 2004). The scale consists of three items rated 1 (Hardly ever) to 3 (Often), which are summed to give a score from 3 to 9. This short version has shown a high correlation ($r = 0.82$) with the 20-item revised UCLA loneliness scale (Hughes et al., 2004). Cronbach’s $\alpha$ in this sample was 0.81.

Risky alcohol use was measured using the alcohol section of The Alcohol, Smoking and Substance Involvement Screening Test (ASSIST). The alcohol section of ASSIST consists of seven questions covering different aspects of alcohol use. Questions 2–6 have numeric ratings attached to the response alternatives, and summing these ratings gives a total risk score for alcohol use ranging from 0 to 39 (World Health Organization, 2006). Cronbach’s $\alpha$ in this sample was 0.71.

2.4 | Statistical analysis

Our general approach to meet the aims of: (1) determining if sleep quality statistically interacts with the other predictors in relation to depressive symptoms (given that we find associations); and (2) explore the functional form of these potential associations and interactions, was to build models of increasing complexity and use repeated cross-
validation to select the best fitting model (Figure 2). We built four separate models for each predictor (loneliness, risky alcohol use, perfectionistic concerns, physical inactivity), two linear and two non-linear models, with and without additive interaction terms. Together these models allowed for the detection of both linear and non-linear interaction effects. Depressive symptoms, sleep quality and all the predictors were modelled as continuous variables in all models. All models were of additive effects.

In total 16 models were fitted, four models for each predictor. Model 1 was an ordinary least squares (OLS) regression model regressing depressive symptoms on the predictor and sleep quality. Model 2 extended the first model by including an interaction term between sleep quality and the predictor. Model 3 was an OLS regression model with 5-knot natural splines on both the predictor and sleep quality variables. Knots were placed at the 5th, 25th, 50th, 75th and 95th percentiles of the full sample distribution (except in the loneliness model, where three knots were used, due to the few scale steps of the UCLA-Ion). Model 4 extended the third model by adding interaction terms between predictor and sleep quality and all of their spline coefficients, creating a tensor spline (Harrell, 2015). All models were adjusted for age, highest level of parental education (as a proxy for socioeconomic status) and gender.

Repeated 10-fold cross-validation with 1000 repeats was used to select the best performing model for each predictor, and to evaluate its simulated replicability (Koul, Becchio, & Cavallo, 2018; Yarkoni & Westfall, 2017; Figure 2). Identical random sampling schemes were used for all cross-validations. Model fit was evaluated on the average out-of-sample $R^2$. The difference in $R^2$ between the final model and the mean out-of-sample $R^2$ from the cross-validations for this model was used as a metric of simulated replication.

For each predictor, the model with the highest $R^2$ was selected as the final model. The parameters of the final models were estimated using the full dataset, and are presented in Table S1. Robust standard errors were used as QQ-plots indicated non-normal residuals for all models. The associations between the predictors, sleep quality and depressive symptoms are presented by plotting the estimated values of depressive symptoms along the continuum of each predictor and sleep quality, along with 95% confidence intervals (CI) for each final model (Figures 3–6). The statistical significance (at an $\alpha$-level 0.05) of the overall associations and interactions were calculated by Wald $X^2$ tests for linear predictors and ANOVAs of all the spline parameters for non-linear predictors (Harrell, 2015). Evidence of non-linearity was assessed by ANOVAs of the non-linear (cubic) parameters of each predictor (Harrell, 2015). The hypothesis of positive interactions between predictors and sleep quality in relation to depressive symptoms was considered supported if the final model(s) showed significant positive interaction.

The PSQI had missing data on items 5b, 5f and 5j for 512 of the respondents, which was handled by imputing the individual mean of items 5b–j.
Sensitivity analyses for the model selection were performed by assessing the Akaike’s Information Criterion (AIC) and the Bayes Information Criterion (BIC) of all models, presented in Table S2. All analyses were performed in R version 4.1.1, the regression models were fitted using the “rms” package.

### RESULTS

We invited 18,973 students, and 4262 (23%) agreed to participate in the study. Most of the sample were from medical (46%) and technical (42%) education programs, 62% were female and the mean age was 26.1 years. Further sample characteristics are presented in Table 1 as percentages and medians (MD) with interquartile ranges (IQR).

#### 3.1 Model selection

For loneliness, risky alcohol use and physical activity, Model 3 had the highest out-of-sample $R^2$ (Figure 2). Model 3 was specified with non-linear main effects for the predictor and sleep quality but no interaction term. For perfectionistic concerns, Model 2, with linear main and interaction effects for perfectionistic concerns and sleep quality, and Model 4, with non-linear main and interaction effects, performed nearly identically and the simpler Model 2 was chosen as the final model. The sensitivity analyses showed that the above models also had the lowest AIC. Using BIC, the same model was chosen for perfectionistic concerns. In contrast, Model 2 (linear interaction) had the
lowest BIC for loneliness, and Model 1 (linear associations with no interaction) had the lowest BIC for risky alcohol use and physical activity (Table S1).

### 3.2 The final models

The estimated associations from each of the final models along with 95% CIs are presented visually in Figures 3–6. Sleep quality was positively associated with depressive symptoms in all the final models, but interacted only with perfectionistic concerns in relation to depressive symptoms. Loneliness showed a positive ($F_{3,4249} = 215.43, p < 0.001$), non-linear ($F_{2,4249} = 15.22, p = 0.0001$) association with depressive symptoms in the final model, but no interaction with sleep quality. Risky alcohol use was also positively ($F_{5,4247} = 8.38 p < 0.0001$), non-linearly ($F_{4,4247} = 3.71 p = 0.0051$) associated with depressive symptoms in the final model, but no interaction with sleep quality. In the final model for perfectionistic concerns, both perfectionistic concerns ($\beta = 0.0861, t = 7.66, p < 0.0001$) and sleep quality ($\beta = 0.2927, t = 9.51, p < 0.0001$) showed significant linear associations with depressive symptoms, with a significant positive linear interaction between perfectionistic concerns and sleep quality ($\beta = 0.0108, t = 6.68, p < 0.0001$). Physical activity showed a positive ($F_{5,4257} = 7.29, p < 0.0001$) and non-linear ($F_{4,4258} = 2.48, p = 0.0418$) association with depressive symptoms in the final model, but no interaction with sleep quality (see Table S2 for full estimates from the final models).

### 3.3 Simulated replicability

The mean difference in R² between the out-of-sample cross-validations and the final models estimated from the full dataset were −0.007 for the loneliness model, −0.009 for the risky alcohol use model, −0.006 for the perfectionistic concerns model, and −0.008 for the physical inactivity model.
4 | DISCUSSION

We analysed data from 4262 Swedish university students to examine if the strength of the associations between loneliness, risky alcohol use, perfectionistic concerns, or physical inactivity and depressive symptoms varied depending on sleep quality, i.e. if there were statistical interactions.

In line with our expectations, loneliness, risky alcohol use, perfectionistic concerns, physical inactivity and sleep quality were all associated with depressive symptoms. We hypothesized that the strength of the associations between these variables and depressive symptoms would vary across levels of sleep quality. In line with our hypothesis, we found a statistical interaction between perfectionistic concerns and sleep quality, indicating that the association between perfectionistic concerns and depressive symptoms is stronger when sleep quality is worse. In contrast to our hypothesis, we found no evidence that the strength of associations between loneliness, risky alcohol use or physical inactivity and depressive symptoms varied depending on sleep quality.

Overall, our hypothesis that the associations between depressive symptoms and several predictors of different kinds (behavioural, psychological and psychosocial) would vary in strength across levels of sleep quality was not supported. Although perfectionistic concerns statistically interact with sleep quality, this interaction was weak, and the association between perfectionistic concerns and depressive symptoms differed only marginally over different levels of sleep quality. As this is a cross-sectional study, causality cannot be inferred. Still even if this was a causal interaction, the clinical significance of this interaction is arguably negligible due to the small effect, at least when considered in isolation. However, earlier studies have found that sleep also interacts with several other risk factors in relation to depression, as is presented in the Introduction. If sleep quality interacts with several risk factors for depression, other than the ones we have investigated, then even small interaction effects could accumulate across different risk factors (Funder & Ozer, 2019) to produce clinically relevant effects on depressive symptoms. This is, however, highly speculative. To investigate this possibility, studies that consider interaction effects between sleep quality and a wider range of potential risk factors, with better control of confounding and reverse causality, are needed.

Our second aim, to explore the best functional form for the association between the predictors and depressive symptoms, was met by considering both linear and non-linear models, with and without interaction terms. For each of the predictors, the model accounting for most of the out-of-sample variance in depressive symptoms was selected as the final model. In the final model for perfectionistic concerns, sleep quality and perfectionistic concerns showed a linear interaction in relation to depressive symptoms. Loneliness, risky alcohol use and physical inactivity all showed non-linear associations with depressive symptoms in their final models, but no interaction with sleep quality. Overall, the final models accounted for a considerable proportion of the variance ($R^2$) in depressive symptoms (Figure 2). However, the differences in explained variance between the final and the other candidate models (linear and non-linear, with and without interaction terms) were small, < 1% across all predictors. This indicates that interactions and non-linearities accounted for little of the individual differences in depressive symptoms, and that most variance was explained by the linear associations of the predictors and sleep quality with depressive symptoms. The sensitivity analyses showed that although the final models all had the lowest AIC, three of them did not have the lowest BIC. This disagreement between selection criteria is interpreted as further evidence of the small differences between the different types of model specifications (linear and non-linear, with and without interaction terms).

Even though non-linearities accounted for little of the overall variance in depressive symptoms, they may still be of importance to accurately describe the associations. Judging from Figures 4 and 6, the associations of risky alcohol use and physical inactivity with depressive symptoms may not be very well described by a straight line. Restricting the analyses to linear associations may obscure details that may be of theoretical interest, such as the J-shaped association between risky alcohol use and depressive symptoms. The decision to allow for non-linearities may also lead to different conclusions about the presence of interaction, as we elaborate on below when comparing our results with prior research.

Our results seem to contrast some earlier cross-sectional studies in that loneliness and physical inactivity did not interact with sleep quality in relation to depressive symptoms (Gillis & El-Sheikh, 2019; Moore et al., 2021; Richardson et al., 2019). These differences between our study and earlier accounts could potentially be explained by different conceptualization and measurements of the constructs. For instance, these earlier studies have focused on sleep duration rather than sleep quality, and social isolation rather than loneliness. Another difference is that these earlier studies did not allow for non-linearities in their models, which could potentially explain the conflicting findings regarding loneliness. It has been shown that non-linear associations can be mistaken for interactions if they are (mis)specified as linear (Belzak & Bauer, 2019). If we restrict our focus only to our linear models of loneliness (Models 1 and 2; Figure 2), the model with an interaction term between loneliness and sleep quality performed better (Loneliness Model 2). Had non-linearities not been considered (as in Models 3 and 4), this would have been taken as evidence of a statistical interaction between loneliness and sleep quality, which would have been in line with prior research (Richardson et al., 2019). The difference in performance between the loneliness model with linear interaction (Loneliness Model 2) and the model with non-linear terms but no interaction (Loneliness Model 3) was very small. When using BIC as a sensitivity analysis for the model selection, the linear interaction model (Loneliness Model 2) was selected as the best fit. Thus, it is hard to determine which of the loneliness models that are closest to any “true” data-generating mechanism, i.e. if loneliness actually interacts with sleep quality, as indicated by prior research, or if the relationship with depressive symptoms is non-linear, as indicated by our results. The small differences in performance between the above discussed models underscore the importance of considering non-linear associations when examining interaction effects. We are not aware of any previous studies investigating interaction effects...
between alcohol use or perfectionistic concerns and sleep quality in relation to depressive symptoms.

4.1 Strengths and limitations

This study has several strengths. We included a large and diverse sample of university students. The use of cross-validation for model selection gives an interpretable model selection metric, as well as a metric for simulated replicability. This enables easy and straightforward comparison of the relative performance of the models, which here showed the small differences in explained variance between the different model specifications. The small difference in $R^2$ between the full model and the out-of-sample cross-validations (the simulated replicability) indicated that our models performed robustly even when applied to data that were not used to fit the models. The difference in $R^2$ between the full models and the out-of-sample replication of the models was less than 1%.

One limitation of the current study is the cross-sectional design, which precludes causal interpretations of the results. For a statistical interaction to be interpreted as causal, all confounding between the outcome and both interacting factors must be accounted for and reverse causation must be ruled out (Lash, VanderWeele, Haneuse, & Rothman, 2021), which was not possible given the cross-sectional design of this study. Another limitation is the use of self-rated measures. Self-ratings are necessary for the measurement of many psychological constructs but may have systematic biases. The ratings of risky alcohol use and physical inactivity may, for instance, be affected by social desirability. Negative thinking associated with depression could also make participants who are more depressed more likely to endorse negatively laden items on other scales, biasing the result towards stronger associations. Further, although we recruited a large and diverse sample, with gender and age distributions that are similar to the overall population of Swedish university students, the generalizability may be affected by the fact that only 23% of the invited students agreed to participate in the study. We also have a high proportion of medical and technical students, which is not representative of the overall Swedish student population. Although we believe that the mechanisms studied work similarly in our sample as in the population overall, we cannot rule out the possibility that the participants differ from the overall population in such a way that the results are not generalizable. Future studies may overcome some of these limitations, for instance by using objective measures of physical activity and sleep.

small differences in explained variance between non-linear models without interaction and linear interaction models highlights the importance of considering non-linear associations when studying interaction effects.

AUTHOR CONTRIBUTIONS

Fred Johansson: conceptualization, methodology, software, formal analysis, investigation, writing – original draft, visualization. Pierre Côté: project administration, supervision, writing – review and editing. Clara Onell: investigation, writing – review and editing. Henrik Källberg: formal analysis, writing – review and editing. Tobias Sundberg: investigation, project administration, supervision – review and editing. Klara Edlund: investigation, project administration, supervision, writing – review and editing. Eva Skillgate: investigation, funding acquisition, project administration, supervision, writing – review and editing.

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CONFLICT OF INTEREST

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The dataset generated and analysed during the current study are not publicly available due to secondary confidentiality and privacy of the participants.

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REFERENCES


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