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*Published in:*
Journal of Affective Disorders Reports

*DOI:*
10.1016/j.jadr.2021.100134

Journal of Affective Disorders Reports 4 (2021) 100134

Contents lists available at ScienceDirect

Journal of Affective Disorders Reports

journal homepage: www.elsevier.com/locate/jadr

Research Paper

# Affect, worry, and sleep: Between- and within-subject associations in a diary study

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ARTICLE INFO

*Keywords:*
Sleep problems
Sleep quality
Bidirectional association
Positive/pleasant affect
Negative/unpleasant affect
And worry

ABSTRACT

*Objectives:* Little is known about the daily associations between affect, worry, and sleep problems, and previous studies did not distinguish differences between persons from differences within persons. We examined bidirectional associations of daily unpleasant affect (UA), pleasant affect (PA), and worry with sleep problems at both the between- and the within-persons level.

*Methods:* The data came from a web-based diary study called "HowNutsAreTheDutch", in which 1,165 respondents filled out an online questionnaire 3 times a day, for 30 consecutive days. Daily levels of affect and worry were calculated by averaging the morning, afternoon, and evening scores. Sleep problems were assessed in the morning, with regard to the previous night. Bidirectional associations between affect, worry, and sleep problems were tested using Dynamic Structural Equation Modeling (DSEM).

*Results:* High UA, low PA, high worry, and poor sleep were strongly associated at the between-person level. At the within-person level, better-than-usual sleep at night significantly predicted lower UA ($\beta$ = -0.31, $p < .001$) and worry ($\beta$ = -0.16, $p < .001$) and higher PA ($\beta$ = 0.29, $p < .001$) during the subsequent day. The effects from daytime affect and worry to sleep the subsequent night were also significant, but considerably weaker.

*Limitations:* Women and highly educated individuals were overrepresented in our sample.

*Conclusions:* Persons who sleep worse than usual at night are likely to experience less PA and more UA and worry the following day. Daytime UA, PA, and worry also predict sleep problems during the following night, but to a lesser extent than the reverse effects.

## 1. Introduction

Sleep problems are common prodromal factors for many kinds of psychopathology, including affective disorders (Baglioni et al., 2011a; Neckelmann et al., 2007; Pigeon et al., 2017). Sleep problems have often been reported to predict symptoms of anxiety and depression, and vice versa (Alvaro et al., 2013; Horváth et al., 2016; Jansson-Fröjmark and Lindblom, 2008; Kalmbach et al., 2017). The association of sleep problems with depression and anxiety may be mediated by daily affective states. Therefore, investigating the link between nightly sleep problems and daily affect is a logical step toward developing more effective strategies to prevent mental health problems.

Several previous studies have investigated associations between daytime affect and self-reported sleep problems during the preceding or following night, and vice versa. Whereas some studies found significant bidirectional associations between affect and sleep problems in clinical samples (Cousins et al., 2011; Talbot et al., 2012), much remains to be learned about the exact nature of the associations. Several findings suggest that sleep problems are among the strongest predictors of unpleasant affect (UA) and pleasant affect (PA) (Bower et al., 2010; McCrae et al., 2008; Sonnentag et al., 2008), and that poor sleep predicts next-day affect rather than the other way around (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013; Simor et al., 2015; Sin et al., 2017). A few studies found that daily affect, particularly PA, predicted fewer sleep problems as well (Kalmbach et al., 2014; Ong et al., 2017; Steptoe et al., 2008).

In addition to UA and PA, worry is likely to be associated with sleep problems. Worry refers to an uncontrollable cognitive process characterized by repetitive thoughts about anticipated potential threats. Whereas

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https://doi.org/10.1016/j.jadr.2021.100134
Received 23 October 2020; Received in revised form 16 February 2021; Accepted 26 March 2021
Available online 28 March 2021

worry is a normal human reaction to stress, chronic worry is a main symptom of generalized anxiety disorder. Although worry is closely linked to UA, it is more specifically related to processes that are assumed to disturb sleep. The perseverative negative thoughts make it difficult to achieve the relaxed mind state required to fall asleep. In addition, worrying may trigger physiological hyperarousal (Borkovec et al., 1998). The cognitive theory of insomnia (Harvey, 2002; Schmidt et al., 2011) asserts that exacerbated worry deteriorates sleep because worrying activates the sympathetic nervous system and hypothalamic–pituitary–adrenal axis, which prepares the body for fight or flight instead of sleep (Brosschot et al., 2007; Kalmbach et al., 2018a). This further illustrates how excessive worrying has been associated with impaired sleep (Åkerstedt et al., 2007; McGowan et al., 2016a). In turn, sleep problems, particularly a short duration of sleep (Kelly, 2002), can lead to more worrying, because lying awake offers an obvious opportunity to think about concerns, and because people may start to worry about their lack of sleep. Taken together, these mechanisms may lead to a mutually reinforcing process Harvey (2002).

Most longitudinal and cross-sectional studies that examined associations between affect, or worry, and sleep used long time intervals between assessments, and did not examine detailed within-person dynamic processes. Furthermore, studies that investigated day-to-day associations between affect and sleep problems at the within-person level did not include worry, and were based on relatively small samples (Bouwmans et al., 2017; Kalmbach et al., 2014; McGowan et al., 2016a; Simor et al., 2015) or short time periods (de Wild-Hartmann et al., 2013; Sin et al., 2017). Therefore, the nature of the associations between affect, worry, and sleep problems requires further investigation. To fill this gap, we used data from a large population-based sample that had reported on UA, PA, worry, and sleep for 30 consecutive days. Sleep was assessed by subjective sleep measures, which have been suggested to be more relevant for affect than objective measures such as actigraphy and polysomnography (Edinger et al., 2000; Rosa and Bonnet, 2000). We hypothesized that (a) sleep problems would be positively associated with UA and worry, and negatively associated with PA at the between-subject level; and (b) at the within persons level, more UA and worry, and less PA than usual during daytime would be associated with more sleep problems the subsequent night, and vice versa.

To obtain valid estimates of the strength of the bidirectional associations of affect and worry with sleep problems, it is important to distinguish between inter-individual (between-person) and intra-individual (within-person) differences. While inter-individual variability has been used to refer to stable traits and variations across persons, intra-individual variability refers to the variability within a person over time and situations Hamaker (2012). Only statistical models that separate within-person effects from between-person effects allow meaningful statements on within-person processes. Thus, dynamic structural equation modeling (DSEM) offers a sophisticated way to estimate multilevel models for intensive longitudinal data, and hence allows the testing of effects of affect and worry on sleep problems, and vice versa, within individuals (Asparouhov et al., 2018; Hamaker, 2017; Hamaker et al., 2018).

## 2. Methods

### *2.1. Participants*

We used longitudinal diary data from the Dutch ongoing study "How Nuts Are The Dutch", which is an ongoing crowdsourcing study that uses an online platform to collect multidimensional mental health data in the general population. Participants were recruited by announcements in local and national media such as radio, television and newspapers, in which they were invited to visit the website www.HoeGekIs.nl. The study was launched in December 2013. The sampling procedure has been described in more detail elsewhere (Krieke et al., 2017). Informed consent was obtained from all participants. Between May 2014 and December 2017, participants could enroll in a diary study in addition to filling out the main questionnaires. The diary study included 1302 participants. Inclusion criteria for the present study were an age of at least 18 years and valid data on at least two of the total 90 measurements. Two diary participants were below 18 years of age and 135 people had fewer than two valid measurements, leaving a sample of 1165 individuals. Based on the Depression–Anxiety–Stress Scale (DASS), 7.2% of the participants in our sample reported mild, 7.9% moderate, and 7.0% severe depression symptom levels in the past week. With respect to anxiety, 3.3% reported mild, 6.4% moderate, and 3.9% severe symptom levels in the past week.

### *2.2. Procedure*

Assessments were prompted at equidistant time points with a six-hour interval in between, with the exact time points depending on participants' sleep–wake schedule. Participants were instructed to pick a sampling schedule that fitted their daily rhythm, with the evening measurement preferably half an hour before their regular bedtime. Three times a day, for 30 days, participants of the diary study received a text message on their smartphone containing a link to an online questionnaire on a secure website. They were asked to fill out the questionnaire immediately after the alert, or, if impossible, within one hour. After an hour, the questionnaire was no longer accessible. More details about the procedure are provided elsewhere (Krieke et al., 2016).

### *2.3. Measures*

The diary questionnaire contained twelve affect items, based on the circumplex model of affect (Feldman Barrett and Russell, 1998; Russell, 1980; Yik et al., 1999), which includes a pleasantness and an activation dimension. Six of the diary items assessed PA and six UA, and each scale contained three activation and three deactivation items. Sleep was assessed once a day (in the morning questionnaire), by means of two items (see Fig. 1). The affect and worry items were part of a diary questionnaire containing 43 items in total, and selected from validated questionnaires supplemented by some newly created items (Krieke et al., 2016, 2017). The new items were based on existing literature as much as possible, but some were slightly reworded in order to adapt them to the specific requirements of an ESM study in an internet sample. Participants could not skip items, because the questionnaire could only be submitted if all questions were answered. Out of 34,950 possible observations (1165 persons x 30 days x 1 assessment per day), 3294 observations (9.4%) were missing. In addition, 4589 observations (13.4%) were removed due to technical errors. The distribution of the number of completed questionnaires was bi-modal as many participants dropped out within the first 20 assessment moments. Given the media attention the study received, the early dropouts may be related to people signing up out of curiosity rather than motivation to finish the whole measurement period (see Krieke et al., 2017, for a detailed analysis). A substantial part of the participants (44.3%) completed in at least 75% of the measurements.

#### *2.3.1. Unpleasant affect*

UA was assessed by means of the activation: items "I feel anxious", "I feel nervous", and "I feel irritable", and the deactivation items: "I feel gloomy", "I feel dull", and "I feel tired". Each item was rated on a visual analogue scale (VAS) ranging from 0 to 100, with 0 representing "not at all", and 100 "very much". Participants answered the question by moving the slider to the correct score. The scale score reflected the mean of the six items. The within-person Cronbach's alpha was 0.76 (see the statistical analysis). For each day, a single UA score was computed by averaging the three daily scores.

#### *2.3.2. Pleasant affect*

PA was measured by the activation items "I feel energetic", "I feel enthusiastic", and "I feel cheerful", and the deactivation items "I feel

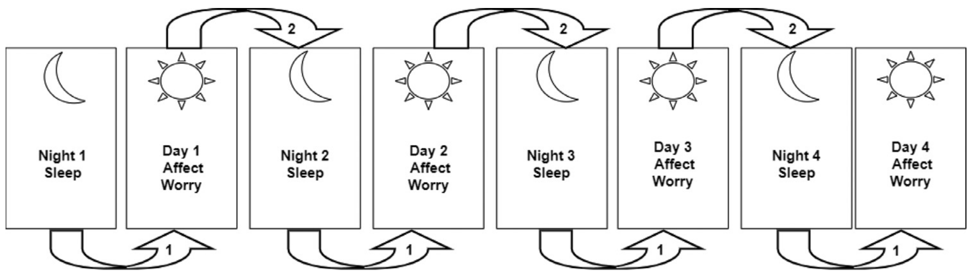


**Fig. 1.** Overview of the study measurements. For 30 consecutive days, affect and worry were measured three times a day, and sleep during the morning.
Arrow 1 - association between sleep and subsequent daytime affect, Arrow 2 – association between affect and worry during the day and sleep during the subsequent night.

relaxed", "I feel content", and "I feel calm". These items were rated on a similar VAS scale as that used for the UA items. The PA scale score was calculated by mean of the six items, and had a within-person Cronbach's alpha of 0.84. For each day, a single PA score was calculated by averaging the three daily scores.

### 2.3.3. Worry

Worry was measured with the item: "I worry a lot". Participants were asked to rate the extent to which this statement was appropriate on a VAS scale ranging from 0 to 100. Average day worry was computed by averaging the three daily scores.

### 2.3.4. Sleep

Two items were used to measure subjective sleep quality: "Did you sleep well?" and "Did you sleep long enough?". Snyder et al. (2018) recently showed that the single sleep item "How would you rate your sleep quality overall?" had strong concurrent, criterion, and convergent validity; an acceptable reliability and the ability to sensitively measure treatment responsiveness and clinically meaningful differences. This suggests that our measure captures the concept of sleep quality well. Participants rated these items on VAS scales ranging from 0 being marked as "not at all" or "too short" to 100 reflecting "very well" or "too long", respectively. The scale score represented the mean of the two items. The correlation between the two sleep items was 0.40, and their within-person reliability was 0.48.

## 2.4. Statistical analysis

We calculated the within-person reliability by combining the item and the day level variance, as described by Nezlek (2017). In the formula below, $\sigma^2_{\text{occasion level}}$ is the occasion level (level 2) variance, $\sigma^2_{\text{item}}$ is the item level (level 1) variance, and p is the number of items in the scale.

$$\text{Item Level reliability } \alpha = \sigma^2_{\text{occasion level}} / \left( \sigma^2_{\text{occasion level}} + \left[ \sigma^2_{item}/p \right] \right)$$

Values between 0.00 and 0.10 reflect virtually no reliability, between 0.11 and 0.40 slight reliability, between 0.41 and 0.60 fair reliability, between 0.61 and 0.80 moderate reliability, and between 0.81 and 1.00 substantial reliability.

The intra-class correlation (ICC) was computed for all variables in the model. The ICC is the ratio of between-person variance to total variance (i.e., the sum of the within-person and between-person variance), and reflects the proportion of the total variance that is due to stable, trait-like, between-person differences. Consequently, 1-ICC indicates how much of the total variance is explained by within-person fluctuations.

Between-and within-person associations between affect, worry, and sleep were tested by means of DSEM, using the Mplus version 8.2. DSEM is suitable for analyzing the structure of repeated measures data. We used a two-level model, in which measurement occasions were nested within people and person-specific random effects were taken into account McNeish and Hamaker (2019). Before using DSEM, all variables (NA, PA, worry, and sleep) were detrended to remove long-term trends (using version 4.0.2 of the R programming language) because trends can inflate autocorrelation estimates Rovine and Walls (2006). DSEM decomposes the data into a within-person and between-person part, and builds each part with its own model (Hamaker et al., 2018) (see Fig. 2). For each variable, individual mean scores across days were centered at the grand mean and entered at the between-person level with correlations modeled between the variables to test for between-person associations. Associations at the between-person level hence reflect differences between individuals based on their mean scores over the whole period. In other words, a positive between-person association between UA and sleep means that individuals who, over the whole time period, scored higher on average than other individuals on UA and also had higher scores on average on sleeping problems. The within-person level associations indicate whether temporal changes in sleep problems predict changes in UA, PA, and worry the subsequent day, and vice versa. Within-person bidirectional associations were tested in two separate models, each involving a different day-night combination. First, we tested whether prior night sleep problems predicted affect and worry the next day. Second, we tested whether daily affect and worry predicted sleep problems the following night. Testing the latter involved shifting the variable so that sleep assessed at time $t + 1$ was aligned with affect assessed at time t (see Fig. 2). Using two separate models was necessary because otherwise one of the effects would be considered contemporaneous and the other temporal, which would hamper the comparability of the coefficients. The within-person effects presented in this article are so-called contemporaneous effects, representing associations between the residuals of the temporal effects (cross-lagged and autocorrelations). Please note that, for associations of sleep with affect and worry, these effects should actually be interpreted as temporal effects because night and day are, by definition, not contemporaneous.

DSEM incorporates Bayesian estimation with uninformative priors (Asparouhov et al., 2018), using two Markov chain Monte Carlo chains (MCMC). Parameter estimates are based on the median of the posterior distribution. Model convergence was determined by the potential scale reduction (PSR) value. A stable PSR value below 1.05 (also known as the Gelman-Rubin-Brooks diagnostic criterion) indicates convergence. We ran a minimum of 20,000 iterations and doubled the number of iterations when stable convergence was not reached. We used the TINTERVAL option of DSEM to account for unequal time intervals between measurements caused by missed measurements. With the TINTERVAL function, a desired time interval between measurements is chosen, which was one day in our study. All available data points were placed in this time interval. Points on the time interval without data are indicated as missing (Asparouhov et al., 2017). Missing data are sampled from their conditional posterior at each iteration of the MCMC algorithm (Asparouhov et al., 2018). This conditional distribution considers the autocorrelation structure of the individual's data into account and ensures consistent estimation as long as data are missing at random (Hamaker et al., 2018).

We used the false discovery rate (FDR) method to account for multiple testing (Benjamini and Hochberg, 1995). Considering that the regression analyses involved four independent variables and four dependent variables (UA, PA, worry, and sleep), there were 16 tests in total. Based on our hypotheses, 12 tests were selected as input for the FDR method (autoregressive effects were excluded). First, the p-values of all statistical tests were ranked from low to high. Thereafter, for each ranked test,

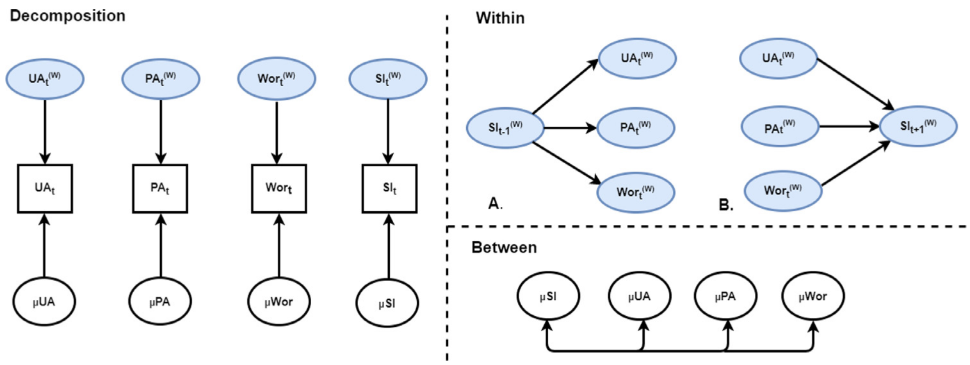


**Fig. 2.** Description of the DSEM model. The left side shows the decomposition into within-person (blue circles) and between-person components; the right side which associations were tested in the model.
UA = Unpleasant affect; PA = Pleasant affect; Wor = worry; Sl = sleep problems; t-1 =preceding day (for UA, PA, and Wor) or night (for Sl); $t$ = current day or night; $t$ + 1= the following night.
µUA, µPA, µWor, µSl = within-person means across all measurements.
$UA^w$, $PA^w$, $Wor^w$ and $Sl^w$ = temporal deviations from the within-person means at a particular day or night.
$A$ = association from sleep problems to affect and worry the next day; $B$ = association from affect and worry to sleep problems the next day.

a FDR corrected significance threshold was calculated with alpha set to 0.05 using the following formula:

$$FDR\ derived\ significance\ threshold = \frac{0.05}{number\ of\ tests/ranking}$$

The number of tests was 12 and the significance threshold for rank was 9, leading to a FDR-derived significance threshold of 0.0375 for all tests (see Supplementary Table S1).

Finally, we performed three sensitivity analyses to explore the robustness of our findings. First, morning measurements of UA, PA, and worry were omitted from the analysis, because morning affect and worry may be artificially associated with reports on the previous night's sleep, which was measured at the same assessment, due to state effects. Second, we only included participants who completed more than 75% of all measurements ($n$ = 517) in the analyses. Third, we ran separate models for each sleep item (i.e., quality and duration) to check whether the findings applied to both aspects of sleep. The study protocol and statistical analysis are provided on the Open Science Framework (https://osf.io/vhknf/).

## 3. Results

### 3.1. Descriptive statistics

In total, 1165 participants (84% females) completed at least two consecutive assessments and were included in the study. The mean age of the participants was 38.6 years (SD 13.2). Of the participants, 82% had a high educational level and 63% had a partner (Table 1). The total number of completed questionnaires was 27,067. The mean compliance rate was 79.9% (SD = 29.4) for affect and 65.8% (SD = 27.7) for sleep. Means and standard deviations (between- and within-subjects) of the variables are presented in Table 2.

For UA, PA, and worry, the ICC was 0.71, 0.62, and 0.72, respectively. This indicates that the between-person variance was larger than the within-person variance; the remaining 29% (UA), 38% (PA), and 28% (worry) were explained by fluctuations within persons. For sleep problems, the ICC was 0.33, indicating that 33% of the variance in sleep problems was explained by differences between individuals and 67% by fluctuations within persons.

### 3.2. Between-person level

#### 3.2.1. Associations between sleep problems, affect, and worry

Both DSEM models converged well; after 12,900 and 11,000 iterations, the PSR value dropped below 1.05 and it remained below 1.03 until the final iteration. The standardized coefficients are presented in Table 3. All associations were significant at the between-person level.

**Table 1**
Demographic characteristics.

| | n ($n$ = 1165) | % |
|---|---|---|
| Age, SD | 38.6 (13.2) | |
| Sex (female) | 975 | 83.7% |
| Male | 190 | 16.3% |
| Education | | |
| High | 957 | 82.1% |
| *University education* | *483* | *41.5%* |
| *University applied science* | *406* | *34.8%* |
| *Higher professional education* | *68* | *5.8%* |
| Middle | 86 | 7.4% |
| Low | 9 | 0.8% |
| Missing and others | 113 | 9.7% |
| Marital status | | |
| Living with partner | 583 | 50.0% |
| *Married living together* | *357* | *30.6%* |
| *Steady partner living together* | *226* | *19.3%* |
| Steady partner not living together | 147 | 12.6% |
| Married not living together | 9 | 0.8% |
| No partner | 324 | 27.8% |
| *Widowed* | *11* | *0.9%* |
| *Divorced* | *68* | *5.8%* |
| *Neither widowed nor divorced* | *245* | *21.0%* |
| Missing | 102 | 9.0% |

SD: standard deviation.

There was a moderate negative association between high UA levels and sleep quality ($\beta = -0.45$, $p < .001$), a moderate negative association between high worry and sleep quality ($\beta$ = -0.39, $p$ < .001), and a strong positive association between PA and sleep quality ($\beta$ = 0.58, $p$ < .001).

### 3.3. Within-person level

#### 3.3.1. Associations between sleep problems and subsequent affect and worry

Temporal changes in sleep quality predicted subsequent changes in UA ($\beta = -0.31, p < .001$), PA ($\beta = 0.29, p < .001$), and worry ($\beta = -0.16$, $p$ < .001), respectively (Table 4). More specifically, an improvement in sleep quality was followed by a decrease in UA and worry, and an increase in PA the following day.

#### 3.3.2. Associations between affect and worry and subsequent sleep problems

Affect and worry predicted sleep problems, and changes in UA, PA, and worry were all significantly associated with subsequent changes in sleep problems (Table 4). High UA and worry during the day were followed by reduced sleep quality; and high PA by an improved quality of

**Table 2**
Descriptive statistics of UA, PA, worry, and sleep.

| | Mean | SD | Within-day SD | Between-person SD | Within-person SD |
|---|---|---|---|---|---|
| UA, 0–100 | 28.2 | 15.8 | 7.47 | 13.7 | 8.38 |
| PA, 0–100 | 55.6 | 14.7 | 8.56 | 11.82 | 9.35 |
| Worry, 0–100 | 34.3 | 23.1 | 10.61 | 20.07 | 12.62 |
| Sleep, 0–100 | 54.4 | 14.9 | [a] | 8.89 | 12.42 |

*UA: Unpleasant affect, PA: pleasant affect, SD: standard deviation.*
[a] -Within-day SD of sleep was not estimated because sleep was measured once per day.Note: Linear time trends were removed from the data.

**Table 3**
Between-person associations between UA, PA, worry, and sleep.

| | UA | | PA | | Worry | |
|---|---|---|---|---|---|---|
| | $\beta$ [95%-CI] | $p$ | $\beta$ [95%-CI] | $p$ | $\beta$ [95%-CI] | $p$ |
| PA | −0.67 [−0.71, −0.64] | <0.001 | – | – | – | – |
| Worry | 0.84 [0.82, 0.86] | <0.001 | −0.60 [−0.64, −0.56] | <0.001 | – | – |
| Sleep | −0.45 [−0.50, −0.39] | <0.001 | 0.58 [0.53, 0.63] | <0.001 | −0.39 [−0.45, −0.33] | <0.001 |

Note: All p values are two tailed. UA: Unpleasant affect; PA: Pleasant affect, $\beta$: standardized coefficient, CI: credible interval.
The FDR derived significance threshold was 0.037.

**Table 4**
Within-person associations between UA, PA, worry and sleep.

| | $UA_t$ | | $PA_t$ | | $Worry_t$ | |
|---|---|---|---|---|---|---|
| | $\beta$ [95%-CI] | $p$ | $\beta$ [95%-CI] | $p$ | $\beta$ [95%-CI] | $p$ |
| Sleep $_{t-1}$ (Sleep to affect and worry) | −0.31 [−0.32,−0.29] | <0.001 | 0.29 [0.28, 0.30] | <0.001 | −0.16 [−0.18, −0.15] | <0.001 |
| Sleep $_{t+1}$ (Affect and worry to sleep) | −0.03 [−0.04, −0.01] | .002 | 0.04 [0.03, 0.06] | <0.001 | −0.03 [−0.05, −0.02] | <0.001 |

Note: All p values are two tailed. UA: unpleasant affect; PA: Pleasant affect, $\beta$: standardized coefficient, CI: credible interval, t-1: preceding night, t: present day, $t + 1$: following night. The FDR derived significance threshold was 0.037.

sleep. The size of the effects of UA, PA, and worry on sleep problems were weaker than the effect sizes of the reverse associations (i.e. from sleep problems to affect and worry).

### *3.4. Sensitivity analyses*

A DSEM analysis excluding morning assessments of affect and worry yielded a pattern of results that were comparable to the main findings. The effects of sleep on affect and worry the following day were somewhat weaker than in the analyses including the morning assessments, but still significant and stronger than the effects of affect and worry on sleep the following night (Supplementary Tables S2.1 and S2.2). Analyses based on only participants who completed more than 75% of all assessments yielded results that were virtually similar to the main findings (Supplementary Tables S3.1 and S3.2). Separate analyses for sleep quality and sleep duration indicated that the main results were primarily driven by the item of sleep quality (Supplementary Tables S4.1 and S4.2). Associations of sleep duration with affect and worry showed the same pattern but were weaker at both the between-person and the within-person level, and the effects of UA and PA on sleep duration were no longer significant (Supplementary Tables S5.1 and 5.2).

## 4. Discussion

### *4.1. Limitations and strengths*

In this study, we investigated how poor sleep predicted unpleasant affect, pleasant affect, and worry the next day, and in turn, how daily affect and worry predicted subsequent sleep problems, using longitudinal intensive data collected in a large population-based sample. Several limitations should be considered when interpreting the results. First, the analytical approach used (DSEM) estimates contemporaneous and temporal (lagged) effects, but the day-and-night nature of our data complicates these notions; and thus caution is warranted when interpreting the effects. More specifically, associations between daytime affect and nighttime sleep are, by definition, lagged because sleep refers to a different time period than affect. Hence, although we reported on within-person effects that are labeled contemporaneous in the DSEM model, the associations of sleep with pleasant affect, unpleasant affect, and worry should be interpreted as temporal (please note that temporal effects in DSEM imply contemporaneous effects too, so do not offer a solution for this problem). Second, unlike normal SEM models, absolute and incremental model fit indices are not yet available for DSEM models, which implies that we were unable to thoroughly test the model fit. Third, women and highly educated individuals were overrepresented in our sample, which might limit the generalizability of the findings to the population at large. Fourth, we did not use a standardized, well-validated sleep measure such as the Pittsburgh Sleep Quality Index (Buysse et al., 1988) or Consensus Sleep Diary (Carney et al., 2012). The two self-report sleep items used in our study are rather global and do not provide potentially relevant information about the nature and causes of poor perceived sleep duration and quality such as insomnia, environmental noise, insufficient time in bed, etc. Thus, the use of more specific sleep measures may reveal patterns that have remained obscure in our study. Fifth, the reliability of the sleep problems scale was relatively low due to the low number of items, which may have reduced the associations of sleep with affect and worry. Sixth, sleep duration (one of the components of sleep problems) was rated on a scale ranging from 0 = too short to 100 = too long, but we did not assess how much sleep was considered optimal, and assumed that higher scores reflected better sleep. Inspection of the raw data revealed that only 1.7% of all sleep duration ratings were higher than 81, which suggests that contamination by too much sleep probably did not have a large influence on our results. In addition, insomnia is more likely to increase the risk of psychiatric and somatic problems than sleeping too long (Roberts et al., 1999; Staner, 2003). Seventh, worry was assessed with a single self-report item, which may have limited its validity. However, Schroder et al. (2019) recently showed that a single item from the Penn State Worry Questionnaire ("I worry all the time") had a similar sensitivity and specificity as the full scale, and a high convergent validity. This item is quite comparable to the item used in our study ("I worry a lot"), which suggests that our measure captures the concept of worry quite well. Eight, our study was designed to investigate continuous mental health dimensions in a general population sample and did not contain clinical information on mental and somatic health conditions. It was therefore not possible to investigate whether and how the presence of depression, anxiety, and physical disorders influenced daily affect and sleep problems.

The notable strengths of our study are, first, that it was based on a large sample and many time points per person, spanning a period of 30 days. Second, we used a statistical model that separated within-person from between-person effects. As opposed to between-person effects, within-person effects provide direct evidence of whether changes in one are preceded or followed by changes in the other, which is a prerequisite for successful clinical intervention strategies to prevent or alleviate mood or sleep problems. Furthermore, between-person effects can help to identify target populations. Third, to investigate whether associations between previous night's sleep and affect/worry may have been biased because the assessment of sleep occurred at the same time as the assessment of morning affect and worry, we performed a sensitivity analysis with affect and worry scores based on afternoon and evening assessments only. Fourth, the small time intervals between the measurements reduced the probability of recall bias.

### *4.2. Basic findings and implications*

At the between-person level, we found a strong positive association of sleeping well with pleasant affect; and moderate negative associations of good sleep with unpleasant affect and worry. These results are in line with previous reports on between-person associations between sleep and affect in diary studies (Simor et al., 2015; Sin et al., 2017).

Generally, our findings at the within-person level were consistent with the hypothesis that better sleep (in terms of both quality and duration) is associated with increased daytime pleasant and decreased unpleasant affect the following day. Differences in the measures used to assess affect and sleep make it difficult to directly compare the results of our study to previous reports. Despite such methodological differences, these findings are consistent with previous reports suggesting that poor sleep predicts low pleasant and high unpleasant affect (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013; Kalmbach et al., 2014; Simor et al., 2015; Sin et al., 2017). Our finding that sleep problems had a larger effect on unpleasant than on pleasant affect the next day deviates from two previous studies that found a significant effect of sleep problems on pleasant but not on unpleasant affect (Kalmbach et al., 2014; Sin et al., 2017). These diverging results may be due to methodological differences. That is, our sample was considerably larger and, as opposed to the previous two studies, our measure of unpleasant affect included an item assessing tiredness, which may have increased the strength of its association between sleep problems. This is because fatigue is a symptom of depression as well as a consequence of sleep problems, and has been reported to play an important role in the association between sleep and affect (Bouwmans et al., 2017).

As mentioned, we found that high unpleasant and low pleasant affect during the day predicted sleep problems the subsequent night, but to a lesser degree than the effect of sleep problems on affect. Kalmbach et al. (2014) also reported associations between daily affect and sleep problems, but with effect sizes that were larger than ours. Why the effects were relatively modest in our sample might be due to a variety of methodological reasons, including chance. This notion is supported by studies that did not find significant effects of affect on sleep problems (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013; Simor et al., 2015); hence, previous findings were not consistent with our results. The small effects of affect on sleep in our study have not been reported before may be caused by power differences. That is, whereas previous studies reporting no significant effects (Bouwmans et al., 2017; de Wild-Hartmann et al., 2013; Simor et al., 2015) had relatively small samples, our study was based on a large dataset and, hence, had larger power to detect small differences.

The size of the effect of sleep on subsequent affect was larger than the effect sizes of affect on subsequent sleep, which supports the notion that poor sleep influences affective problems more strongly than the other way around. This pattern is in alignment with several longitudinal studies in which sleep at baseline predicted anxiety and depression at follow-up more strongly than the opposite effects (Jansson-Fröjmark and Lindblom, 2008; Kalmbach et al., 2018b), and insomnia often appears before the onset of affective disorders (Johnson et al., 2006; Ohayon and Roth, 2003). Altogether, this provides rather robust evidence that poor sleep more often precedes than follows from affective problems.

With regard to the associations between sleep problems and worry, our results differ from those reported by McGowan et al. (2016a), who found that daytime worrying predicted poor sleep but not vice versa. Again, this inconsistency might be due to sample and power differences: whereas McGowan et al. used a small sample of women with high trait worry, we used a large population-based sample of men and women. Furthermore, McGowan et al. measured sleep using the Insomnia Severity Index, which was designed to assess the severity of nighttime and daytime insomnia. We used a more general measure of sleep quality and sleep duration, which may be differentially related to worrying.

Subjective sleep measures, like the one used in our study, correspond only partially to more objective sleep parameters such as when assessed by means of actigraphy and polysomnography; for example, previous research suggests that short sleepers tend to report more and insomniacs less sleep, than when assessed objectively (Fernandez-Mendoza et al., 2011). Because the assessment of subjectively experienced sleep is based on self-reports, there is a possibility that the mood state at the time of assessment biases the reported sleep problems. Whereas objective sleep measures have the advantage of being insensitive to reporting bias, they are more difficult to collect and may be less ecologically valid. Moreover, perceived sleep quality is likely to affect and be more affected by affect and worry than objective sleep measures (Edinger et al., 2000; Rosa and Bonnet, 2000). Nevertheless, it would be interesting to investigate whether the patterns found in our study can be replicated with objective sleep measures. Preferably, such a study would combine standardized self-report sleep measures with objective sleep assessments.

Although the temporal associations found in our study do not necessarily imply causal pathways, such pathways are certainly conceivable. A possible mechanism through which sleep problems may influence affect and worry is that poor sleep impairs executive function (Nilsson et al., 2005). Subsequently, decreased activation of or functional connectivity in the brain may contribute to a diminished ability to inhibit or regulate emotional processes and, thus, promote maladaptive repetitive thoughts and attentional biases (Baglioni et al., 2010). In addition, REM sleep plays an important role in memory consolidation and emotion regulation Goldstein and Walker (2014) and sleep problems have been found to predict high cortisol reactivity to stress (Mrug et al., 2016), which has been associated with the development of depression and anxiety (Adam et al., 2014; Kuhlman et al., 2020). Furthermore, the bidirectional association found between worry and sleep problems is consistent with the cognitive model of insomnia Harvey (2002), which states that daytime worrying contributes to sleep problems which, in turn, increase intrusive negative thinking, autonomic arousal, and emotional distress, and through these, worry again.

The within-person variance of sleep was larger than the between-person variance in our study, which suggests substantial day-to-day variation in sleep reports, larger than the variation in affect and worry. A likely explanation is that a night of short and poor sleep tends to be followed by a night of longer and better sleep due to accumulated sleep need. The amount of intraindividual variability of sleep is age- and sex-dependent; young females report the greatest within variability in sleep (Dillon et al., 2015). Our study sample consisted mostly of females (83%) of a relatively young age, which may have contributed to the high within-person sleep variability found in this study.

Sleep problems predict not only temporary unpleasant affect and worry, as we found in our study, but are also known to precede more persistent affective problems such as depression and anxiety disorders (Baglioni et al., 2011a; Jansson-Fröjmark and Lindblom, 2008; Narmandakh et al., 2020; Neckelmann et al., 2007; Pigeon et al., 2017). In turn, our and other findings suggest that anxious arousal predicts insomnia symptoms (Horváth et al., 2016; Oh et al., 2019). Moreover, stronger day-to-day bidirectional influences of sleep and affect have been reported to increase the likelihood of developing a depressive disorder (de Wild-Hartmann et al., 2013). Therefore, treatment of sleep problems may prevent the onset or exacerbation of anxiety and depression, and vice versa (Baglioni et al., 2011b; Manber et al., 2008; McGowan et al., 2016b). Unfortunately, many individuals with sleep problems do not report these to their physicians and hence do not receive adequate treatment Leger and Poursain (2005), and the same is also true for people suffering from anxiety and depression (Alonso et al., 2018; Thornicroft et al., 2017).

To conclude, we examined associations between affect, worry, and sleep problems at the between- and within-person level, and found consistent evidence for day-to-day bidirectional associations of affect and worry with sleep problems in the general population. Although the effects of sleep on affect and worry were stronger than the effect in the opposite direction, our study suggests that any intervention that prevents or ameliorates sleep problems, unpleasant affect or worry not only benefits that particular symptom, but the other symptoms as well, and might turn a negative spiral into a more positive one.

## Declaration of Competing Interest

The authors declare no conflicts of interest.

## Author note

This paper used data from the “How Nuts Are The Dutch” (HND) project. The HND project is funded by a VICI grant (no. 91812607) received by Peter de Jonge from the Netherlands Organization for Scientific Research (NWO-ZonMW) and by the University Medical Center Groningen Research Award 2013.

## Author’s contributions

A.N., A.O., A.R., and P.J. designed the study, M.M. provided data analysis tools and support, and A.N. performed the statistical analysis. A.N and A.O. drafted the manuscript; P.J., A.R., and M.M. provided feedback. All authors discussed the results and had final approval of the submitted paper.

## Acknowledgements

We are grateful to everyone who participated in this research or worked on this project to make it possible. Furthermore, we thank Stefan R.A. Konings for his valuable advice on the use of the R programming language.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jadr.2021.100134.

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