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Poor sleep quality predicts psychotic-like symptoms: an experience sampling study in young adults with schizotypal traits

Simor P, Báthori N, Nagy T, Polner B. Poor sleep quality predicts psychotic-like symptoms: an experience sampling study in young adults with schizotypal traits

Objective: Psychotic-like experiences (PLEs) are unusual experiences such as perceptual abnormalities and delusional-like thoughts that resemble the symptoms of psychosis at the sub-clinical level. PLEs are associated with sleep complaints in healthy and clinical samples; however, evidence for day-to-day associations between poor sleep and subsequent PLEs under naturalistic conditions is scarce. We hypothesized that poor sleep quality would predict next days' PLEs, and vice versa, daytime PLEs would be associated with worse subsequent sleep quality.
Method: Seventy-three university students with moderate to high levels of positive schizotypy participated in an experience sampling study. Participants rated their sleep each morning, as well as PLEs and affective states during the day over 3 weeks.
Results: Multilevel regression models indicated that poor sleep quality predicted increased PLEs the following day. Poor sleep was linked to negative daytime mood that partially mediated the associations between sleep quality and next days' PLEs. Furthermore, PLEs were enhanced in the evening as compared to daytime reports. The prediction of poor sleep quality by previous days' PLEs was negligible.
Conclusions: The results are consistent with the position that sleep-related interventions might reduce the risk of psychosis, especially in individuals that tend to experience psychotic-like phenomena and negative affect.

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Key words: experience sampling; negative affect; psychotic-like; schizotypy; sleep

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Significant Outcomes

- Poor subjective sleep quality and short sleep predicted next days' psychotic-like experiences.
- More psychotic-like experiences during the day predicted lower sleep quality the following night to some extent, but explained only a negligible portion of the variance.
- The temporal associations between sleep quality and psychotic-like experiences were partially mediated by negative mood.

Limitations

- Sleep quality was measured by self-report questionnaires.
- Lack of objective measures (e.g., actigraphy) of sleep quality.
- High ratio of female participants.

Introduction

Psychotic-like experiences (PLEs) are sub-clinical expressions of unusual thoughts, perceptual anomalies, and paranoid ideation that are common in the general population, with prevalence rates ranging from 4% to 7% (1–4). Beyond

phenomenological similarities, PLEs are analogous to psychotic symptoms in that they are associated with similar socio-environmental risk factors (5, 6) and neurocognitive dysfunctions (6–9). As PLEs constitute a risk factor in the normal population for developing psychosis (1, 10, 11), identifying the factors that contribute to such experiences is crucial to understand the etiology, progression, and relapse of psychotic disorders. Furthermore, the study of PLEs in non-clinical populations is devoid of the confounding effects of disease-related factors such as hospitalization, medication, or stigmatization (12).

Poor subjective sleep quality refers to the experience of non-restorative, insufficient, and fragmented sleep leading to sleepiness, fatigue, and tiredness on waking and throughout the day (13). Epidemiological studies indicate that poor sleep quality as measured by self-report questionnaires is associated with PLEs (14, 15). Moreover, poor sleep quality is a strong predictor of the occurrence and persistence of PLEs according to longitudinal assessments of both non-clinical and clinical participants (16, 17), and sleep complaints also predict the relapse of psychosis in patients with schizophrenia spectrum disorders (18), suggesting that the association between sleep quality and psychotic-like phenomena does not respect boundaries of diagnostic categories.

In line with these longitudinal observations, experimental evidence suggests that sleep deprivation has a causal effect on PLEs. For instance, Giesbrecht and colleagues (19) showed that one night of sleep deprivation increased dissociative experiences that share many features with PLEs (20–22). Further studies have shown that total sleep deprivation induced PLEs (23–25), but the mediating role of negative affect following experimental sleep deprivation (26, 27) remains to be clarified. Importantly, negative affect has been shown to mediate the relationship between sleep quality and PLEs (15, 28). In a recent study, even a moderate sleep loss due to sleep restriction appeared to increase PLEs as compared to a regular sleep condition, and the effect was mediated by stress, worry, and negative affect (29).

These studies offer valuable insights into the effects of sleep deprivation on the occurrence of PLEs; however, they cannot address the question whether lower sleep quality precedes PLEs under naturalistic conditions. In fact, experimentally induced sleep loss is different from poor sleep quality in many regards: the latter is characterized by difficulties in initiating and maintaining sleep, nocturnal and early morning awakenings, hyperarousal, and presleep rumination (30). Experience sampling methods (ESM) can provide insight into the temporal associations between intra-individual variation in subjective sleep quality and PLEs (31, 32). To date, however, only two studies have used ESM to investigate the daily variation of sleep quality and subsequent PLEs. In one study involving patients diagnosed with schizophrenia, impaired sleep quality predicted subsequent psychotic symptoms (33), and in another study with adolescents recruited from the community, poor sleep was associated with increased paranoia the next day (34). Moreover, in line with theories emphasizing the role of emotional reactivity in the development of psychosis (35), negative affect emerged as a mediator in both studies. On the other hand, whether PLEs during the day precede sleep complaints has only been scarcely investigated. Daytime paranoid ideation did not result in poor sleep quality among adolescents (34), while the effect of daytime psychotic symptoms on subsequent sleep quality was not reported in the study involving patients with schizophrenia (33). Several studies suggest negative affect and stress during the day impact subsequent sleep physiology and sleep quality (36–38), supporting the notion of a reciprocal relationship between daytime experiences and sleep. Accordingly, PLEs and sleep quality may also show a reciprocal relationship.

In order to investigate the bidirectional link between subjective sleep quality and daytime PLEs, we conducted a 3-week long experience sampling study. A non-clinical sample of young adults showing moderate to high levels of positive schizotypy (which reflects proneness to PLEs (39)) participated in the study. It has been shown that PLEs show subtle daily fluctuations (40, 41), but the temporal associations between sleep quality, negative affect and psychotic-like phenomena so far have not been examined among healthy adults showing moderate to high levels of positive schizotypy. We hypothesized that poor subjective sleep quality would predict next-day PLEs, and vice versa, increased daytime PLEs would result in lower sleep quality during the night that follows. Moreover, we took into consideration the influence of mood, as negative emotionality seems to be a prominent factor mediator of temporal co-occurrence of sleep quality and daytime PLEs (29, 33, 34).

Aims of the study

- To perform an experience sampling study over a 3-week period in a non-clinical sample.
- To examine the bidirectional, temporal associations between subjective sleep quality and psychotic-like experiences under naturalistic conditions.

- To examine the influence of mood as a putative mediator in the association between sleep quality and next days' psychotic-like experiences.

Material and methods

Participants

Participants were selected from a large number (N = 774, 552 (71%) females, age = 18–42 years, $Mean_{age}$ = 21.16, SD_{age} = 2.28) of undergraduate university students of the Eötvös Loránd University who completed an online questionnaire before being invited to participate in the study. The online survey included standardized scales on personality (42), chronotype (43), sleep quality (44), schizotypy (45), and depression (46). The students received partial course credit for completing the survey. The students completing the online survey were given the possibility to provide their contact details (email) in case they were interested in participating in further experiments. Of the 774 respondents, 595 individuals gave their email.

In order to enroll individuals prone to report PLEs, the scores on the questionnaire were evaluated, and those who had intermediate to high levels of positive schizotypy (39) were considered to take part in the experience sampling study. Thus, we selected those participants who scored at least 4 on the unusual experiences (UE) subscale of the *short Oxford-Liverpool Inventory of Feelings and Experiences* (sO-LIFE) (45) as eligible for the study. (A score of 4 belonged to the 1st tertile of the distribution of the UE subscale score ranging from 0 to 12 points). Additional exclusion criteria were as follows: (i) current or prior history of mental, chronic somatic, neurological, or sleep disorders (according to self-report); (ii) intake of medications, except for contraceptives; (iii) experience of any extremely stressful events over the last 6 months that might have influenced sleep quality and daytime affect; (iv) consumption of more than six units of alcohol (47) per week; (v) total score on the Beck Depression Inventory higher than 24 (which indicates moderate depression according to norms established in Hungary (46)). A total of 261 participants fulfilled these criteria and received an invitation to take part in the 3-week long experience sampling study, of which 75 responded to participate and came to the laboratory for a personal appointment with the study assistant. Two participants were excluded from the analysis (due to missing data and hospitalization during the study period). This way, the data of 73 participants (61 females, age = 18–25 years, M = 20.46, SD = 1.43) were included in the final analysis. Participants were compensated with additional course credit points. The study was approved by the Hungarian Ethical Committee for Psychological Experiments (EPKEB 2017/121), and participants provided written-informed consent.

Procedure

In the first interview, participants were informed that the aim of the study was to investigate the relationship between sleep, daytime mood, and personality with short questionnaires that were to be completed every day during the 3-week study period. The 21-day long period started the day after the first personal interview. Self-report questionnaires were completed via an online interface three times a day: after awakening, at noon, and in the evening. Individuals could access the morning questionnaire between 05:00 and 11:00 am, the second questionnaire between 12:00 and 17:00 pm, and the evening questionnaire between 19:00 pm and 02:00 am. Participants received reminder emails for each time slot to complete the questionnaires. Reminders were always sent within the first half of the specific time windows. (For example, reminders for the questionnaires that were active between 12:00 and 17:00 h were sent between 12:00 and 14:30.) In case of the morning questionnaire, they had to rate their subjective sleep quality and report their sleep schedules (bedtimes, sleep latency, wake up times, estimated sleep duration). In the daytime surveys, they were asked to report their experiences concerning the last couple of hours that passed between the current and the previous survey.

The daily questionnaires included additional items that helped us to prevent participants from recognizing the real purpose of the study and avoid performance bias. The morning questionnaire included two items related to dreaming, and the daytime questionnaires included five items on mind-wandering (48), caffeine intake, as well as items and open-ended questions regarding the stressful events during the day. The questionnaires at each time point (morning and daytime ones) consisted of 21 items. After the end of the study period, participants received an online survey to report any kind of extreme event that might have profoundly influenced sleep and daytime mood (e.g., accident, loss, illness) during the study period. In addition, we inquired (by open-ended questions) whether participants recognized the purpose of the study. Participants were debriefed upon request. None of the participants recognized the real aim of the study.

Instruments

Schizotypal personality traits were assessed with the Hungarian adaptation of the Short Oxford-Liverpool Inventory of Feelings and Experiences (sO-LIFE (45)). The questionnaire consists of 43 self-report yes/no items that group into four subscales: (i) unusual experiences, (ii) Cognitive Disorganization, (iii) Introvertive Anhedonia, and (iv) Impulsive Nonconformity. Here, we only used the unusual experiences subscale in our statistical analyses, which had acceptable reliability in the sample (Cronbach's alpha = 0.69). This reliability coefficient is comparable to what has been obtained in a large German community sample (0.71) (49), and somewhat lower than what has been reported in a sample of twin pairs from the UK (0.80) (45). In our sample, variability of positive schizotypy was restricted due to the enrollment procedure (see Participants), thus Cronbach's alpha is likely to be underestimated (50).

We used the Hungarian version of the Groningen Sleep Quality Scale (GSQS-H) to measure subjective sleep quality each morning during the study period. The 14-item questionnaire assesses last nights' sleep quality with true/false items (e.g., I feel like I slept poorly last night and I got up in the middle of the night;), and higher total scores indicate poorer subjective sleep quality. In previous studies, the GSQS-H proved to be a suitable instrument to quantify subjective sleep quality in both healthy individuals and patients with sleep complaints (51, 52), and in the present study, it showed good internal consistency (Cronbach's alpha = 0.84). In addition to the GSQS-H, participants were asked to respond to single items regarding their bedtimes, sleep latency (in minutes), and wake up times. *Subjective sleep duration* was extracted by computing the number of minutes that passed between bedtime + sleep onset and wake up time.

The Daytime and the Evening Questionnaires consisted always of the same items measuring PLEs. The specific items (See Table 1) were selected and adapted for our study design from two different questionnaires (40, 53) developed for the momentary assessment of psychotic-like states and unusual experiences. The eight items of the scale covered paranoid thoughts (e.g., I think that in the last couple of hours people have been saying or doing things to annoy me.), cognitive disorganization (e.g., I think that in the last couple of hours I have had difficulty controlling my thoughts), and perceptual anomalies (e.g., In the last couple of hours my sight, hearing or sense of smell have felt different from usual, it has been unusually strong or strange). The items measuring PLEs were rated on an 8-grade Likert scale from 0 (almost never) to 7 (almost always). The scale showed good internal consistency (Cronbach's alpha = 0.83), and principal component analyses supported the unidimensionality of the scale (the first component explained 47% of the variance, whereas the 2nd and 3rd components only 12% and 11% respectively). Moreover, participants had to complete the adapted version of the five-item mind-wandering scale (48), they were asked to mention any kind of extreme event (e.g., accident, exam, job interview) that occurred that day, and to report their mood and arousal, separately by 8-point single item Likert scales (e.g., My mood in the last couple of hours was... 0—very bad, depressed, distressed, 7—very good, joyful, very positive). In addition to these items, they were asked to report whether they took medications the last 24 h, and to indicate the amount of caffeinated beverages and alcohol they consumed the last 24 h.

Data analyses

All analyses were performed in R (R Core Team) (54) using the lme4 package (55). Data and code to replicate the analyses are openly available here: https://osf.io/vx4y2/. Our data had a hierarchical structure with variables nested within individuals

Table 1. Items assessing psychotic-like experiences (PLEs)

Psychotic-like experience	Source	Domain
1. In the last couple of hours, my thoughts have been strange or unusual	Cristobal-Narvaez et al.(40)	Disorganization
2. In the last couple of hours, my sight, hearing or sense of smell have felt different from usual, it has been unusually strong or strange	Cristobal-Narvaez et al.	Perceptual anomalies
3. In the last couple of hours, familiar things have seemed strange and unusual	Cristobal-Narvaez et al.	Perceptual anomalies
4. I think that in the last couple of hours, I have had difficulty controlling my thoughts	Cristobal-Narvaez et al.	Disorganization
5. I think that in the last couple of hours, people have been saying or doing things to annoy me	Mason et al.(53)	Paranoia
6. In the last couple of hours, I have found it difficult to think clearly	Mason et al.	Disorganization
7. In the last couple of hours, my thoughts have been sometimes so strong that I could almost hear them	Mason et al.	Perceptual anomalies
8. In the last couple of hours, it has been distressing to be with others, because I have been bothered by the idea that they were watching me	Mason et al.	Paranoia

and within days, violating the assumption of independence across data points. Therefore, we applied linear mixed-effects models with random intercepts for day and participant (i.e. day nested within participant ID), and fixed slopes for the predictor variables detailed below. Model parameters were calculated by the restricted maximum likelihood method, and model fits (using the maximum likelihood method) were compared by the Akaike information criterion (AIC) and by the marginal and conditional R^2, the former indicating the variance explained by the fixed predictors, the latter reflecting the proportion of variance explained by the fixed and the random factors together (56).

The first aim of the study was to examine whether sleep quality predicted PLEs on the next day. As a first step, we examined a model (Model 1) that consisted of the following potential confounders: age, gender and positive schizotypal traits as measured by the unusual experiences subscale of the sO-LIFE. As positive schizotypy is conceptualized as the tendency to experience anomalous perceptions and to hold bizarre, odd beliefs, we expected that this trait will positively predict reporting PLEs (39, 53). We included the unusual experiences score in the models predicting PLEs, as our aim was to model day-to-day variation in PLEs over and above trait-like differences. Moreover, positive schizotypy has been reported to correlate with poor sleep (e.g., (14)); thus, in order to control for a trait-level association between positive schizotypy and self-reported sleep quality, the unusual experiences score was also included in the models predicting day-to-day fluctuation in subjective sleep quality.

In Model 2, we included sleep quality (daily GSQS-H scores), subjective sleep duration, and time of day (daytime vs. evening) as additional predictors. To examine the influence of mood as a putative mediator of the association between sleep quality and next-day PLEs, we added the daily ratings of mood as a predictor (Model 3) and examined the change in coefficients ((57)). This method consisted of verifying whether our measures of sleep quality (GSQS-H scores and subjective sleep duration, separately) were linked to next day's mood and then comparing the coefficients between the total effect of sleep quality on next-day PLEs (controlling for age, gender, positive schizotypal traits, and time of day) and the direct effect of sleep quality on PLEs with mood added as a predictor. The indirect effect is calculated as the difference between the estimates of the models without and with the mediator (33).

Next, we investigated the reverse of the above hypothesis, that is, whether daytime PLEs predicted sleep quality the following night. We followed the same strategy as above, but in this case GSQS-H scores and subjective sleep duration were used as separate outcome variables. Age, gender, and unusual experiences of the sO-LIFE were entered as predictors in Model 1. PLEs averaged across the two assessment points were added as predictors in Model 2, and mood was entered as an additional predictor in Model 3. As the residuals were not normally distributed, we applied bootstrapping (58) with 1000 repetitions and computed the bootstrapped confidence intervals and p values for the model parameters.

Results

Adherence and descriptive results

All 73 participants completed the 3-week long study period, and 27% of the participants responded to every survey. Of the possible 4599 entry points, 4269 were completed, thus the proportion of missing data was very low (~7%). The rate of missing data was low in all sampling periods: 6% in the morning, 10% in daytime, and 5% in the evening. Table 2 shows the descriptive statistics for age, gender, trait-like unusual experiences, as well as the 3-week averages of subjective sleep quality, subjective sleep duration, and PLEs. The day-to-day variation of sleep quality, mood, and daytime PLEs was remarkably high within individuals (See S1 in Supplement). Therefore, the analyses of the temporal associations between these variables are feasible in the present sample. Inspection of intraclass correlations indicated that 13% of the variance of sleep quality, 27% of the variance of subjective sleep duration, and 53% of the variance in PLEs was explained by differences

Table 2. Descriptive statistics of the assessed variables (N = 73)

Variable	Range	Mean	SD
Age (years)	18–25	20.47	1.42
Sleep quality (GSQS)	0–14	3.74	3.23
Sleep duration in hours	0–10.65	6.51	1.74
PLE in the afternoon	0–40	7.09	7.86
PLE in the evening	0–56	4.43	8.10
Ratings of Mood	0–7	4.25	1.79
Unusual experiences (OLIFE-UE)	4–11	6.27	1.8

Descriptive statistics summarizing raw values of the examined variables. Apart from the Age and unusual experiences scores, mean and standard deviation reflect the values across all assessments collected over the study period. Values in case of Sleep quality, Psychotic-like experiences, Mood, and unusual experiences correspond to raw scores. Higher scores in Sleep quality and Ratings of Mood refer to poorer sleep, and more positive mood respectively. GSQS, Groningen Sleep Quality Scale; PLE, psychotic-like experiences,sO-LIFE-UE, unusual experiences subscale of the Short Oxford-Liverpool Inventory of Feelings and Experiences questionnaire.

Table 3. Age, gender, positive schizotypy, time of day, previous nights' sleep quality, sleep duration, and daytime mood predicting psychotic-like experiences

	Model 1			Model 2			Model 3		
	Unstd. *b* (SE)	CI	*P* value	Unstd. *b* (SE)	CI	*P* value	Unstd. *b* (SE)	CI	*P* value
Age	−0.23 (0.5)	[−1.25 to 0.71]	0.652	−0.21 (0.49)	[−1.17 to 0.74]	0.67	−0.23 (0.47)	[−1.13 to 0.72]	0.62
Gender	1.70 (1.96)	[−2.24 to 5.60]	0.386	1.84 (1.93)	[−2.00 to 5.57]	0.34	1.98 (1.83)	[−1.49 to 5.65]	0.28
sO-LIFE-UE	0.25 (0.42)	[−0.62 to 1.05]	0.556	0.25 (0.41)	[−0.62 to 1.09]	0.55	0.34 (0.39)	[−0.42 to 1.07]	0.39
Time of Day: Evening				0.64 (0.17)	[0.30 to 0.97]	**<0.001**	0.46 (0.16)	[0.14 to 0.78]	**0.005**
Sleep Quality				0.31 (0.04)	[0.27 to 0.42]	**<0.001**	0.24 (0.04)	[0.17 to 0.32]	**<0.001**
Sleep Duration				−0.18 (0.09)	[−0.3 to −0.003]	**0.043**	−0.15 (0.08)	[−0.3 to 0.02]	0.074
Mood							−1.28 (0.06)	[−1.40 to −1.17]	**<0.001**
Marginal/Conditional R^2	0.009/0.710			0.030/0.711			0.113/0.730		
AIC	17855.955			17331.529			16931.633		

AIC, Akaike Information Criterion; sO-LIFE-UE, unusual experiences subscale of the Short Oxford-Liverpool Inventory of Feelings and Experiences questionnaire.

between individuals (and 87%, 73%, and 47% of the variance of sleep quality, sleep duration, and PLEs, respectively, was due to differences within individuals over the three-week study period).

Prediction of PLEs by previous nights' sleep quality

As shown in Table 3, age, gender, and the proneness to unusual experiences were not associated with daily fluctuations of PLEs (Model 1). When entered as predictors (Model 2), sleep quality, subjective sleep duration, and time of day were significantly associated with daytime PLEs. More specifically, poorer sleep quality and shorter subjective sleep duration were predictive of more PLEs the following day, and significantly more PLEs were reported in the evening compared to the afternoon. Mood, entered in Model 3 as an additional predictor, also showed a significant effect, in that negative mood was associated with increased PLEs. As the estimates of sleep quality and subjective sleep duration showed robust changes between Model 2 and Model 3, we examined the influence of mood as a potential mediator between subjective sleep quality and next-day PLEs, as well as between subjective sleep duration and next-day PLEs.

Mood was predicted by sleep quality (lower sleep quality was linked to worse mood: $b = -0.08$, SE = 0.01, $P < 0.001$) after controlling for the effects of age, gender, trait-like unusual experiences, and time of day. Although the direct effect of sleep quality remained significant after the inclusion of mood as a mediator ($b = 0.24$, $P < 0.001$), based on the change of the regression coefficient of sleep quality, mood accounted for 31.4% of the total effect of sleep quality on next-day PLEs (see Fig. 1/a).

Similarly, mood was predicted by subjective sleep duration (shorter sleep duration was linked to worse mood: $b = 0.08$, SE = 0.02, $P < 0.001$) after controlling for the effects of age, gender, trait-like unusual experiences, and time of day. The direct effect of sleep quality remained significant after the inclusion of mood as a mediator ($b = -0.31$, $P < 0.001$), and mood accounted for 26% of the total effect of sleep duration on next-day PLEs (see Fig. 1/b).

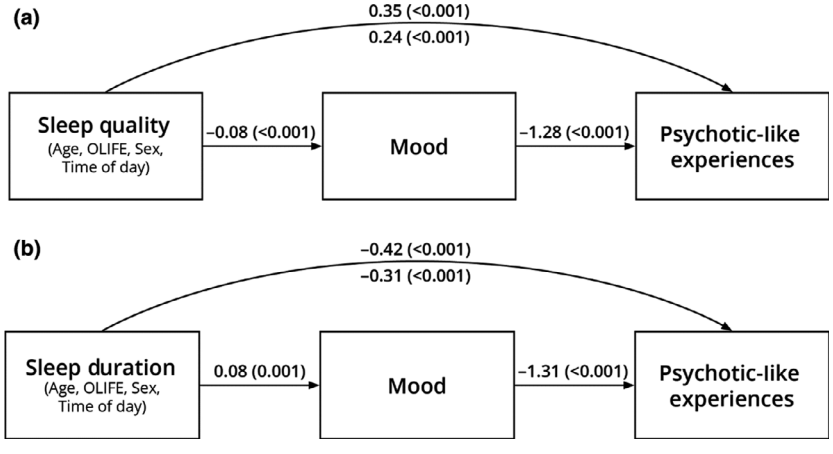

Fig. 1. The association between Sleep Quality and PLEs with mood as a mediator. Total (above the curved line) and direct (below the curved line) effects of Sleep Quality (a), and Sleep Duration (b) on next day's PLEs, and the indirect associations controlling for the effects of age, gender, trait schizotypy (OLIFE), and time of day are shown by unstandardized *b*-values, and *P*-values in parenthesis.

Table 4. Age, gender, positive schizotypy, previous day's PLE's predicting sleep disruption and sleep duration

	Model 1			Model 2			Model 3		
	Unstd. *b* (SE)	CI	*P* value	Unstd. *b* (SE)	CI	*P* value	Unstd. *b* (SE)	CI	*P* value
Sleep Quality (GSQS-H)									
Age	−0.02 (0.11)	[−0.22 to 0.19]	0.873	−0.04 (0.11)	[−0.17 to 0.24]	0.738	−0.04 (0.11)	[−0.17 to 0.25]	0.735
Gender	−0.30 (0.42)	[−1.11 to 0.59]	0.482	−0.48 (0.42)	[−0.24 to 0.40]	0.256	−0.49 (0.42)	[−0.30 to 0.36]	0.253
sO-LIFE-UE	−0.01 (0.09)	[−0.19 to 0.17]	0.908	−0.02 (0.09)	[−0.20 to 0.15]	0.817	−0.02 (0.09)	[−0.20 to 0.16]	0.808
PLE's				0.04 (0.02)	[0.01 to 0.07]	**0.017**	0.04 (0.02)	[0.01 to 0.07]	**0.022**
Mood							−0.01 (0.06)	[−0.11 to 0.13]	0.841
Marginal/Conditional R^2	0.001/0.117			0.009/0.121			0.009/0.122		
AIC	7044.362			6516.225			6522.030		
Sleep Duration									
Age	−0.24 (0.07)	[−0.4 to −0.09]	**0.002**	−0.01 (0.11)	[−0.39 to −0.11]	**<0.001**	−0.01 (0.11)	[−0.40 to −0.11]	**<0.001**
Gender	−0.27 (0.29)	[−0.87 to 0.29]	0.367	−0.22 (0.29)	[−0.79 to 0.33]	0.442	−0.22 (0.29)	[−0.82 to 0.35]	0.462
sO-LIFE-UE	−0.01 (0.06)	[−0.12 to 0.10]	0.927	−0.01 (0.06)	[−0.12 to 0.11]	0.910	−0.01 (0.06)	[−0.12 to 0.11]	0.971
PLE's (day)				0.02 (0.01)	[−0.03 to −0.001]	**0.046**	0.02 (0.01)	[−0.03 to 0.00]	0.060
Mood							0.00 (0.03)	[−0.05 to 0.05]	0.933
Marginal/Conditional R^2	0.043/0.273			0.050/0.272			0.050/0.272		
AIC	5147.356			4800.182			4807.541		

Prediction of subjective sleep quality by daytime PLEs

As detailed in Table 4, day-by-day fluctuation of sleep quality was not associated with age, gender, and trait-like unusual experiences (Model 1). PLEs in the afternoon were significantly associated with subsequent sleep quality (upper panel); however, the model including age, gender, positive schizotypy, and daytime PLEs explained only a small portion (0.009%) of the variance of sleep quality (Model 2). After the inclusion of the ratings of mood (Model 3), PLEs remained significant predictors, but explained variance and model fit did not change considerably. The estimates of PLEs were not modified from Model 2 to Model 3 suggesting that mood was not mediating the links between PLEs and sleep quality. Similar findings emerged in case of sleep duration with respect to PLEs that showed a significant association with sleep duration but contributed with less than 1% to the explained variance (see lower panel of Table 4). Gender and trait-like unusual experiences were not linked to, but age was negatively associated with sleep quality explaining ~4% of the variance (Table 4).

Discussion

The aim of the present study was to examine the bidirectional associations between subjective sleep quality and psychotic-like experiences (PLEs) during a 3-week period in a group of young individuals showing moderate to high positive schizotypy. Our findings indicate that subjective sleep quality predicts next days' PLEs: poorer sleep quality and shorter sleep were associated with increased PLEs the following day (see left panels of Fig. 2). Furthermore, lower sleep quality was linked to more negative ratings of daytime mood, and negative mood partially mediated the link between sleep quality and PLEs, as well as the association between sleep duration and PLEs. Our data do not convincingly support a bidirectional relationship: although PLEs showed weak (and significant) associations with sleep quality and sleep duration the next night, PLEs explained only a negligible proportion (<1%) of the variance in subjective sleep quality and duration, therefore the short-term effects of daytime PLEs on sleep quality does not seem to be clinically meaningful (see right panel of Fig. 2).

These findings are in line with the accumulating evidence supporting a link between sleep quality and PLEs (14, 15). Beyond the consistently reported associations between sleep quality and PLEs in cross-sectional studies (59–61), sleep disturbances seem to precede and predict the appearance of PLEs in non-clinical populations and individuals at high risk for psychosis (16, 17, 62–64). Here, we extended these longitudinal findings by showing that day-to-day fluctuations in PLEs were related to the subjective sleep quality and sleep duration of the preceding night. Previous studies have shown that profound changes in sleep either reflected by symptoms of insomnia (65), induced by experimental sleep deprivation (66), or sleep restriction (29) appear to facilitate PLEs. The present study suggests that even moderate changes in subjective sleep quality in naturalistic conditions are associated with increased vulnerability to experience psychotic-like phenomena the following day. Interestingly, our sample on average was characterized by relatively short sleep duration

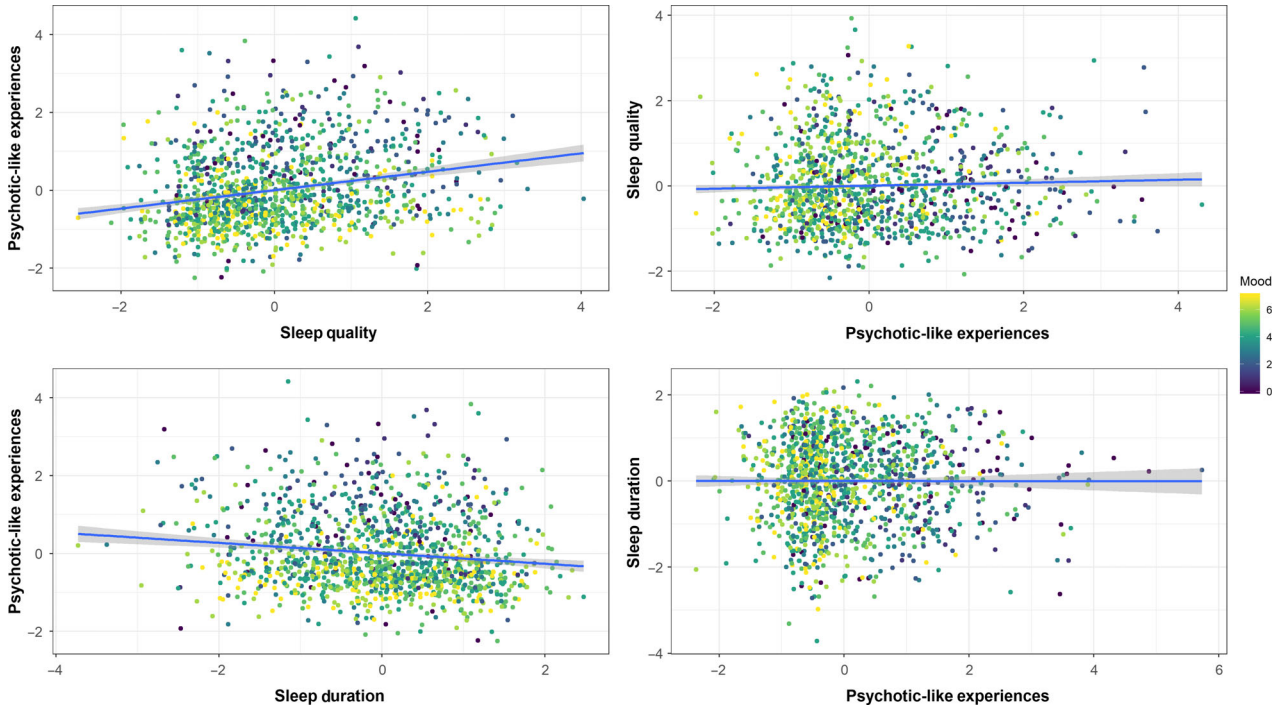

Fig. 2. Visual representation of the associations between sleep quality and PLEs. The left panels show the associations between daytime psychotic-like experiences and sleep quality/sleep duration the night before, and the graphs on the right show the links between psychotic-like experiences and sleep quality/sleep duration the night that follows. Higher scores in sleep quality indicate poorer sleep. Points with warmer and colder colors indicate positive and negative ratings of mood respectively. Note that the warmer colored points (reflecting better mood) are more prominent in case of lower PLEs. Raw values were transformed to *z*-scores for visualization.

(mean = 6.5) that is below the average sleep duration of university students (67). This indicates that our sample did not obtain a sufficient amount of sleep that may also be considered a risk factor, especially in individuals with schizotypal tendencies (14, 59). Future studies may examine whether sleep-related interventions can reduce the risk of psychosis, especially in high-risk populations that exhibit PLEs and PLE-related distress associated with impaired sleep (59). Promising data of a recent randomized controlled trial indicated that a digital cognitive behavioural therapy for insomnia was not only effective in ameliorating insomnia but also reduced PLEs (paranoia and hallucinations). In line with the present findings, changes in sleep quality mediated a large proportion of changes in PLEs, while changes in PLEs mediated only a small amount of change in sleep quality (65).

More negative ratings of daytime mood partially mediated the association between sleep quality and next days' PLEs in line with the detrimental effect of poor sleep on daytime mood (29, 68, 69). Furthermore, this finding is in accordance with two previous experience sampling studies that reported a key role for negative affect in mediating the temporal association between sleep quality and daytime PLEs (33, 34).

Interestingly, positive schizotypal personality traits, that is, the trait-like susceptibility to experience psychotic-like phenomena were not predictive of the rate of PLEs reported during the study period. Although this finding may appear surprising, questionnaires focusing on PLEs on a dispositional vs. state-like manner might not necessarily capture the same phenomenon (70). Alternatively, including only individuals with at least moderate positive schizotypal traits might have masked the influence of trait positive schizotypy on daily PLEs. Future studies may enroll participants with low levels of positive schizotypy to disentangle dispositional and state-like aspects of psychotic-like phenomena.

The mechanism linking sleep quality and daytime PLEs is far from being clarified. Future studies examining objective sleep parameters might provide more insight into the role of sleep in next days' PLEs. For instance, altered sleep spindling, assumed to reflect thalamocortical dysfunctions, were evidenced in schizophrenia patients (71) and were also linked to sub-clinical schizotypal traits (72, 73). Nevertheless, as sleep spindles are remarkably stable features (74), it remains unanswered whether subtle, night-to-night changes in sleep spindling are predictive of the next days' functioning. Moreover, impaired sleep regulation as reflected by

microarousals and reduced slow frequency activity (75) might compromise the restorative capacity of sleep and negatively influence daytime cognition and affect (76). In this case, the negative consequences of impaired sleep regulation should increase as a function of time spent awake (due to higher sleep pressure). In fact, we found increased PLEs in evening assessments as compared with daytime ones, in line with the findings of a recent study reporting increased delusional thinking and paranoid symptoms in the evening compared to the morning after sleep deprivation (77).

Albeit on a statistical level, daytime PLEs were linked with subsequent sleep quality, the negligible amount of the explained variance casts doubts on a bidirectional relationship between sleep quality and PLEs. Moreover, sleep quality was not predicted by daytime ratings of mood. These findings are in line with previous data indicating an unidirectional relationship with respect to day-to-day fluctuations in sleep quality and negative affect (68, 69). We should note however, that our sample consisted of healthy participants and day-to-day fluctuations in sleep quality, PLEs and affective states were still in a non-pathological range. Therefore, future studies should examine whether bidirectional links exist in pathological conditions. Furthermore, although the association between PLEs and subsequent sleep quality was rather weak, we may not rule out the possibility that such small effects could accumulate in the long-term and such small effects might indeed become clinically meaningful over longer time scales (78).

Among the limitations of our study, we need to emphasize that our findings concern only subjective sleep quality, as no objective measures of sleep were applied. Since the shared variance between subjective and objective measures of sleep is remarkably small (79), the assumptions regarding the mechanisms linking sleep quality and PLEs remain to be speculative. Moreover, the fixed time frames provided for subjective reports might have induced retrospective biases and veiled the more dynamic and subtle fluctuations of PLEs and emotional states. Real-time ecological momentary assessments would improve the sampling technique. In addition, daytime mood was measured only with a single item. Although this approach is not uncommon in experience sampling studies (80, 81), future studies would benefit from a more refined measurement of mood states. Finally, our sample involving students and mainly female participants limits the generalizability of our results that should be verified by future studies with a more heterogeneous sample with respect to age, gender, and education. In light of potential gender differences in schizophrenia and PLEs, replication with samples including more male participants would be worthwhile. Male gender was positively associated with PLEs in one meta-analysis (OR = 1.12) (1), but not in a more recent one (OR = 1.01) (2), whereas it is well established that schizophrenia has a higher incidence in males (82). Moreover, it has been suggested that the development of psychosis differs by gender: women might be more prone to develop psychosis via an affective pathway, due to increased emotional reactivity (35), while a cognitive pathway to psychosis with more negative symptoms seems to be more likely in men (83).

In spite of these limitations, our study is the first to examine the links between day-to-day variations in sleep quality, mood, and PLEs in a non-clinical community sample involving a relatively long, prospective assessment period. Our findings highlight the association between subjective sleep quality and next days' functioning and indicate that under naturalistic conditions, subtle fluctuations of subjective sleep quality are predictive of more PLEs the following day.

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Disclosure statement

The authors have no conflicts of interest to declare.

Author contribution

PS designed the study, analyzed the data, and wrote the manuscript. NB collected and analyzed the data and wrote the manuscript. TN analyzed the data and wrote the manuscript. BP designed the study, analyzed the data and wrote the manuscript.

Data availability statement

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