The role of rumination and stress in women's sleep: Evidence from a diary study

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Abstract

Women are recognized to report poorer sleep compared to man, with a wide-ranging consequence for their physical and mental health. Recently, research has started to focus on psychological factors to account for such gender-dependent disparities. Preliminary evidence indicates that poor sleep is often related to stress and use of maladaptive emotion regulation strategies, such as rumination. However, since prior research has mainly examined the association of sleep quality with either stress or rumination, little is known about their potential combined effect. In this one-week diary study, we investigated how daily- and trait-levels of stress and rumination interact to predict sleep quality in 166 healthy women.

The results from multilevel modeling revealed a significant negative association between daily pre-sleep rumination and sleep quality. By contrast, daily stress was not significantly associated with sleep quality, nor did its interaction with pre-sleep rumination. At the trait level, perceived stress and its interaction with brooding rumination were significantly associated with poor sleep quality.

Overall, our findings highlight the importance of diary study designs for deepening our understanding of how stress and rumination are jointly associated with sleep in women. More broadly, the present study contributes to feminist scholarship on health by emphasizing the need to address the gendered dimensions of psychological processes that affect health outcomes.

Keywords: sleep, rumination, stress, women, experience sampling, diary.

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1. Introduction

Sleep quality (SQ) is a critical component of both physical (Luyster et al., 2012; Medic et al., 2017) and psychological well-being (Scott et al., 2017; Weinberg et al., 2016). In recent years, growing attention has been paid to gender-specific differences in sleep patterns (Fatima et al., 2016; Madrid-Valero et al., 2017; Varghese et al., 2020). Consistent evidence has shown that women report poorer sleep compared to men, with important implications for their physical and mental health. This disparity persists even after accounting for socio-demographic, lifestyle, and mental health variables (Singareddy et al., 2012; Lindberg et al., 1997), as well as for biological influences like hormonal fluctuations (Pengo et al., 2018), and work-related stressors such as job demands, long hours, work–family conflict (Sekine et al., 2006). Accordingly, large-scale population studies (e.g., Fatima et al., 2016) have suggested the need to further investigate women's vulnerability to poor SQ, emphasizing that existing sociodemographic, biological, and clinical factors do not fully account for the observed gender specificities in SQ.

Within psychological functioning, rumination is a well-established predictor of sleep-related outcomes (for a systematic review and meta-analysis, Clancy et al., 2020). Rumination is defined as a maladaptive emotion regulation (ER) strategy characterized by repetitive, negative, self-focused thinking about stressful events (Nolen-Hoeksema et al., 2008). Notably, research has distinguished between reflection and brooding (Treynor et al., 2003): The latter involves persistently dwelling on negative thoughts about oneself, situations, or actions and thus represents the more maladaptive form (Treynor et al., 2003; Watkins, 2004). Brooding rumination has been associated with increased sleep onset latency, reduced total sleep time, and poorer subjective SQ (Guastella & Moulds, 2007; Nota & Coles, 2015). Crucially, it is more prevalent among women (for a meta-analysis, Johnson & Whisman, 2013), highlighting a potentially gendered pathway through which psychological factors may influence sleep.

Brooding rumination can be understood within the broader framework of perseverative cognitions, which refer to the repeated and prolonged cognitive representation of stressors (Brosschot et al., 2006). According to prominent conceptualizations of sleep mechanisms (Harvey, 2002; Harvey et al., 2005), such cognitions around bedtime interfere with the sleep initiation process and compromise overall SQ. Pre-sleep rumination, a state-level form of perseverative cognition occurring before sleep (involving negative thoughts, often focused on past events or future concerns), has been identified as a particularly relevant psychological mechanism influencing sleep patterns. A

substantial body of evidence confirms that pre-sleep rumination is associated with delayed sleep onset latency (SOL), reduced sleep duration, and impaired SQ (Guastella & Moulds, 2007; Nota & Coles, 2015; Thomsen et al., 2003; Zoccola et al., 2009; for a review, see Clancy et al., 2020).

A possible reason why pre-sleep rumination may be particularly maladaptive for sleep is the so-called 'pre-sleep cognitive arousal' – a stress-related arousal beyond the presence of an actual stressor – associated to rumination at or around sleep onset (Espie, 2007; Harvey et al., 2005). Pre-sleep cognitive arousal has been shown to disrupt sleep patterns by delaying SOL and compromising overall SQ both in patients with insomnia (e.g., Lichstein & Rosenthal, 1980; Wicklow & Espie, 2000) and normal sleepers (Hall et al., 1996; Gorgoni et al., 2021; Guastella & Moulds, 2007; Wuyts et al., 2012; Yeh et al., 2015). Additionally, ruminative thoughts may carry the influence of daily stressors over into the evening and night (Berset et al., 2011), prolonging physiological activation elicited by those stressors (Cropley et al., 2013; Van Laethem et al., 2016). According to the *Perseverative Cognition Hypothesis* (Brosschot et al., 2006), the spillover of daily stress and daily rumination into the evening period may increase cognitive arousal at bedtime and interfere with the downregulation necessary for restful sleep (Morin et al., 2003). This process seems particularly relevant in individuals with high trait-level rumination, who tend to exhibit heightened stress reactivity and engage in prolonged brooding over stressors, thereby perpetuating their distress (Moberly & Watkins, 2008; Smyth et al., 2013).

Several studies have demonstrated significant associations between perceived stress, rumination, and poor sleep outcomes (Berset et al., 2011; Guastella & Moulds, 2007; Li et al., 2019; Otto et al., 2022; Van Laethem et al., 2016; Tousignant et al., 2019; Zoccola et al., 2009). However, most of this research has been either cross-sectional (e.g., Berset et al., 2011) or experimental (e.g., Guastella & Moulds, 2007). Few studies have used diary study designs to investigate within-person variations in sleep outcomes as a function of daily rumination and stress, and even fewer have investigated the combined and cumulative effect of both daily and trait rumination and stress on sleep. For instance, using a convenience sample of healthy individuals, Åkerstedt et al. (2012) demonstrated that daily fluctuations in pre-sleep rumination around stressors predicted corresponding variations in next-day SQ over a six-week period. Notably, after controlling for pre-sleep rumination, the relationship between daily stress levels and SQ was no longer significant. Van Laethem et al. (2016) found that perseverative cognition mediated the relationship between daily stress and daily SQ (indexed by both subjective and objective sleep parameters) across multiple time points.

Zoccola et al. (2009) further demonstrated that both trait and state stressor-specific rumination interacted to predict longer SOL following an acute psychosocial stressor. Finally, Vahle-Hinz et al. (2014) have examined the relationship between work-related stress, work-related rumination, and restful sleep during both weekdays and the weekend. Findings showed that work-related rumination was associated with restful sleep on weekends but not on workdays, while no mediation effects of work-related stress on restful sleep via work-related rumination were observed. Overall, these studies provide important evidence concerning the potential causal mechanisms underlying daily fluctuations in SQ.

Despite the growing attention to rumination and stress as critical psychological determinants of SQ, little is known about the joint effects of these variables on women's SQ. On the one hand, existing studies have mostly examined either stress or rumination. For instance, using a one-week daily diary design, Lee et al. (2013) identified a relationship between stress and sleep disturbances in female college students. Winzeler et al. (2014) found that pre-sleep arousal mediated this association in a 14-day diary and actigraphy study conducted on 145 women. In more detail, their results showed that somatic pre-sleep arousal mediated the relationship between stress and poor SQ at the between-participant level, while cognitive pre-sleep arousal (i.e., a form of perseverative cognition) mediated this relationship within participants. Finally, Chow et al. (2017) reported that gender differences in sleep were mediated by co-rumination (i.e., a dyadic communication style involving extensive discussion of problems primarily focusing on negative feelings). On the other hand, studies focusing on women's SQ have mostly assessed the broad construct of ER rather than rumination specifically (Racine et al., 2013, Hoag et al., 2016; Vafapoor et al., 2018).

2. The Present Study

The present study aims to address these gaps by investigating the relationship between trait- and state-level rumination and stress and SQ in women using a daily diary-based design. In other words, the main goal of the study is to examine simultaneously trait-level tendencies and day-to-day variations in stress and rumination and their association with women's SQ.

To this purpose, we adopt a repeated measures design assessing women's perceived stress levels, pre-sleep rumination, and SQ at three time points over a week (i.e., weekend, beginning of the week, midweek). At each time point, daily stress levels were assessed asking women to answer a

questionnaire in the evening, while they rated their use of pre-sleep rumination and SQ in a subsequent, morning assessment.

We hypothesized that (H1) both pre-sleep rumination and daily stress would be associated with poorer SQ. Specifically, we expected that women reporting higher pre-sleep rumination and higher stress levels on a given day would experience worse sleep that night. A second hypothesis is that (H2) the negative impact of daily pre-sleep rumination on SQ would be exacerbated by daily stress. Specifically, we expected to observe a stronger negative relationship between pre-sleep rumination and SQ on a given night in those women experiencing higher levels of stress on the preceding day. Third, we hypothesized that (H3) women reporting higher average levels of brooding and perceived stress at the trait level would experience worse SQ across the overall observation period. Finally, we expected that (H4) the association between brooding and poor SQ would be stronger in women with higher average levels of trait stress.

3. Method

3.1. Sample

A community sample of 176 women participated in the study. Ten participants who reported a psychopathological diagnosis were excluded. The final sample thus consisted of 166 women (mean age = 41.08; SD = 15.24; age range = 18-67).

Participants' education levels ranged from junior high school (1.9%), senior high school (28%), university with a bachelor's degree (19.9%), university with a master's degree (36%), to post-university education (7.5%). Additionally, 1.9% of respondents reported a different qualification not included in the previous categories (e.g., a double degree or vocational school training). Regarding occupational status, 58.4% of participants were employed, 24.2% were students, 6.8% were working students, 1.2% were unemployed, and 9.3% were housewives.

3.2. Measures

3.2.1. Trait Measures

Sleep Quality. The Pittsburgh Sleep Quality Index (PSQI; Buysse et al., 1989; Italian version: Curcio et al., 2013) is a 19 item self-report measure to

assess subjective sleep quality (during the previous month). The items tap seven domains of sleep difficulties (range of subscale scores: 0-3): sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medications, and daytime dysfunction. A total score is obtained by computing the sum of these seven components (range: 0-21), with higher scores indicating poor sleep quality. In our study, Cronbach's alpha was 0.674 and McDonald's omega was 0.699, but they increased respectively to 0.745 and 0.758 after two components (medication use and daytime dysfunction) were removed (Zhang et al., 2020). The PSQI adopts a cut-off score of 5 to distinguish between good and poor sleep. In our sample, 37.3% of participants scored below 5, indicating good SQ. An additional 17.5% scored exactly 5, while 33.6% scored between 6 and 10, and 11.4% between 11 and 15.

Brooding Rumination. The Brooding sub-scale of the Ruminative Response Scale (RRS; Nolen-Hoeksema & Morrow, 1991; Italian version: Palmieri et al., 2007) was used. It consists of 5 items rated on a four-point Likert scale ranging from 1 (= never) to 4 (= always). In the present study, Cronbach's alpha was 0.697 and McDonald's omega was 0.702.

Perceived Stress. The Perceived Stress Scale (PSS; Cohen et al., 1983; Italian version: Mondo et al., 2021) consists of 10 items that measure the individual's levels of general stress. The respondents are asked to rate ten statements about their feelings and thoughts during the last month using a 5-point Likert scale ranging from 0 (= never) to 4 (= very often). Cronbach's alpha was 0.843 and McDonald's omega was 0.845.

3.2.2. Daily Measures

Sleep quality. Four items from the Consensus Sleep Diary (CDS; Carney et al., 2012) were used. The items covered the following domains: a) number of nocturnal awakenings (never; 1-2 times; 3-4 times; 5-6 times; more than 6 times); b) difficulties returning to sleep after nighttime awakenings; c) feeling rested upon waking in the morning, and d) overall perceived sleep quality. All items, except for the first one, were rated on a 7-point Likert scale ranging from 1 (not at all) to 7 (very much). A composite score (i.e., sum) was computed, with higher scores indicating worse sleep quality. Cronbach's alphas and McDonald's omegas for each measurement (i.e., weekend, beginning of the week, midweek) were as follows, respectively: $\alpha = 0.787$, $\omega = 0.821$; $\alpha = 0.758$, $\omega = 0.796$; and $\alpha = 0.731$, $\omega = 0.777$.

Pre-sleep rumination. Three items on a 7-point Likert scale from 1 (= not at all) to 7 (= very much) were used, asking participants to report how much they indulged in rumination before falling asleep. Cronbach's alphas and McDonald's omegas for weekend, beginning of the week, and midweek

assessments were as follows, respectively: α = 0.886, ω = 0.897; α = 0.862, ω = 0.876; and α = 0.865, ω = 0.877.

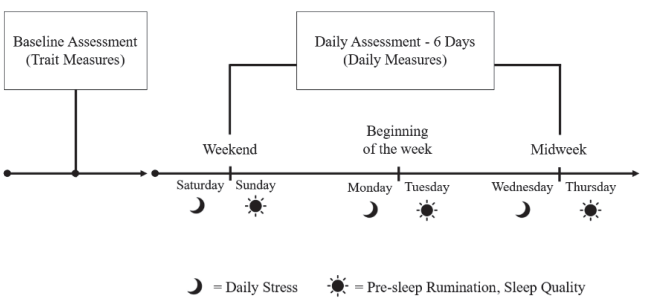
Perceived stress. We used the items of the Perceived Stress Scale (PSS; Cohen et al., 1983; Italian version: Mondo et al., 2021) described above. The instructions and the temporal framing of the items were modified asking participants to report the stress they experienced during the day. Cronbach's alphas and McDonald's omegas for weekend, beginning of the week, and midweek assessments were as follows, respectively: α = 0.858, ω = 0.865; α = 0.870, ω = 0.874; and α = 0.880, ω = 0.882.

3.3. Procedure

Participants were recruited through advertisements posted on social networks and by worth of mouth. Participation in the study was without any monetary compensation. Informed consent was obtained from each participant according to the Declaration of Helsinki (2008).

First, participants completed an initial questionnaire that included trait-assessment measures and questions concerning socio-demographic information. They were also asked to indicate whether they had any psychopathological diagnoses. After participants completed the initial questionnaire, a 1-week diary study including six measurements was conducted. The participants were asked to complete two brief online questionnaires at three time points over the week: weekend (Saturday/Sunday), the beginning of the week (Monday/Tuesday), and midweek assessment (Wednesday/Thursday). First, the participants were asked to answer a questionnaire in the evening to rate the levels of stress they experienced during the day; they were then asked to answer a second questionnaire including measures of rumination and SQ upon awakening the next morning. This procedure is displayed in Figure 1.

Fig. 1 – *Visualization of study design*



Concerning the evening assessments, participants were allowed to answer the questionnaire from 8:45pm to 1:30am, while concerning the morning assessments, from 6:00am to 1:00pm. However, the instructions asked them to try to complete the questionnaire within an hour and a half of waking up.

3.4. Statistical Analysis

First, descriptive statistics and Pearson bivariate correlations were computed, and repeated measures ANOVAs were conducted to inspect whether stress, SQ, and rumination levels varied across the week. Then, due to the data's hierarchical structure (i.e., days nested within individuals), we conducted a multilevel analysis using the *nlme* package (Pinheiro et al., 2020) in R.

Following Bliese's (Bliese, 2012) recommendations, we began by calculating the intra-class correlation (ICC) coefficient for each daily variable to evaluate the proportion of total variance due to between-person differences rather than day-to-day fluctuations within individuals. As a second step, we tested our hypotheses by running a multilevel model. We specified a linear mixed-effects model as follows:

Level 1 (days):

$$\text{Sleep}_{ij} = \beta 0_j + \beta 1_j \cdot \text{Pre-sleep Rumination}_{ji} + \beta 2_j \cdot \text{Daily Stress}_{ji} + \beta 3_j \cdot (\text{Pre-sleep Rumination}_{ji} \times \text{Daily Stress}_{ji}) + \beta 4 \cdot \text{Week Moment}_{ij} + \epsilon 0_{ji}$$

Level 2 (individuals):

$$\beta 0_j = \gamma 00 + \gamma 01 \cdot \text{Brooding}_j + \gamma 02 \cdot \text{Stress}_j + \gamma 03 \cdot (\text{Brooding}_j \times \text{Stress}_j) + u 0_j$$

$$\beta 1_j = \gamma 10 + u 1_j$$

In this model, the outcome at Level 1 (Sleep$_{ji}$), representing a person j's score on SQ at the time point i, was modeled as a function of a random intercept $\beta 0$; the individual-level predictors that vary daily, including pre-sleep rumination (Rumination$_{ji}$), daily stress (Stress$_{ji}$), and their interaction (Pre-Sleep Rumination$_{ji}$ × Daily Stress$_{ji}$); the week moment (Week Moment$_{ji}$); a random error term (ϵ_{ji}) to capture day-specific deviations in SQ that are not explained by the model predictors. At Level 2, we modelled the variability in the intercept ($\beta 0$) as a function of person-level (i.e., between-person) predictors, including trait brooding (Brooding$_j$) and trait stress (Stress$_j$), and their interaction (Brooding$_j$ × Stress$_j$); a random intercept $u0_i$, allowing each person to have their unique baseline level of SQ; a random slope $u1_i$ for pre-sleep rumination, allowing each person to have their unique impact of daily pre-sleep rumination on sleep.

Additional specifications of the model, including the fixed and random effects selection and the centering strategies, are detailed in the Supplemental Material. Information regarding attrition and handling of missing data is also reported in the Supplemental Material.

4. Results

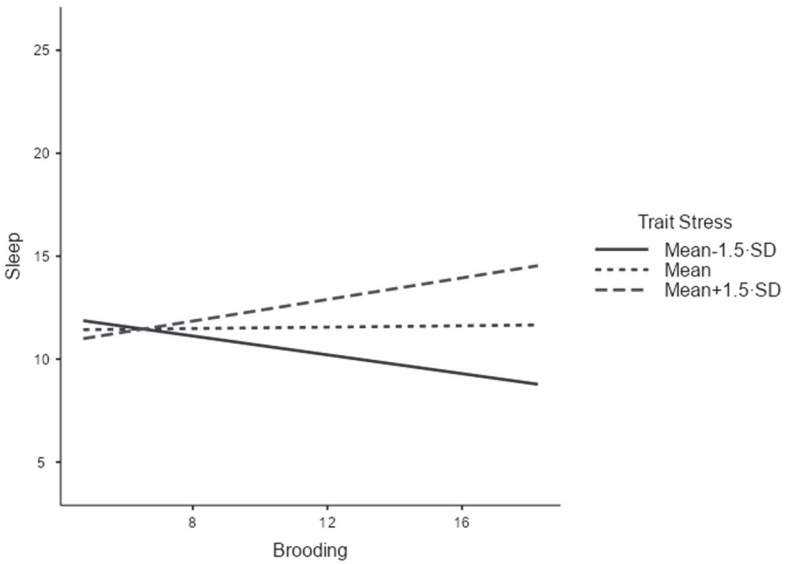
Descriptive statistics and bivariate correlations are reported in Table 1. Repeated measures ANOVAs showed that daily perceived stress increased over the course of the week, $F(2,330) = 6.04$, $p = 0.003$, $\eta^2 partial = 0.035$. In more detail, the participants reported higher levels of stress in the midweek assessment compared to the weekend. However, no significant difference emerged either in daily SQ, $F(2,330) = 0.847$, $p = .430$, $\eta^2 partial = 0.005$, or pre-sleep rumination, $F(2, 330) = 0.105$, $p = .891$, $\eta^2 partial = 0.001$.

The results from the mixed-effects model are presented in Table 2, including both fixed and random effects. In terms of model fit, the marginal R^2 (indicating the proportion of variance explained solely by the fixed effects) was 0.159, while the conditional R^2 (indicating the proportion of variance explained by both fixed and random effects) was 0.532.

The analysis revealed that daily pre-sleep rumination was significantly associated with SQ: On days when women reported higher levels of pre-sleep rumination relative to their own weekly average, they also experienced lower sleep SQ. Trait stress also showed a significant positive association with sleep disruptions, suggesting that participants with higher average level of trait stress, compared to the sample-grand mean, reported more frequent SQ. In contrast, daily stress and trait brooding rumination did not show any significant relationship with SQ.

The interaction between brooding and trait stress was significant, suggesting that individuals with higher levels of trait stress were more vulnerable to the disruptive impact of brooding on their sleep. Simple slopes analyses indicated that the relationship between brooding and sleep was significant and positive at high levels of trait stress (i.e., +1.5 SD; B[SE] = 0.26[0.11], t = 2.31, p = .022). In contrast, this association was not significant at low (i.e., -1.5 SD, B[SE] = 0.23[0.16], t = -1.430, p = .155) and average levels of trait stress (i.e., M, B[SE] = 0.02[0.10], t = 0.175, p = .861). This effect is displayed in Figure 2. In contrast, no significant interaction was found between daily pre-sleep rumination and daily stress on SQ.

Figure 2 – *The moderating effect of Brooding Rumination and Trait Stress on Daily Sleep*



Note: Higher sleep scores indicate worsened sleep quality.

Table 1 – Descriptive statistics and bivariate correlations among study variables

	M	*SD*	*Min*	*Max*	1	2	3	4	5	6	7	8	9	10	11
Trait Measures															
1. PSQI	6.11	3.20	.00	15.00											
2. RRS-B	2.25	.54	1.00	3.60	.080										
3. PSS	2.10	.62	.40	3.80	.315**	.540**									
Daily Measures - Weekend															
4. Sleep	2.87	.94	1.00	6.50	.446**	.269**	.283**								
5. Pre-sleep Rumination	2.51	1.45	.11	7.00	.457**	.445**	.386**	.448**							
6. Stress	1.48	.73	.00	3.70	.035	.204**	.300**	.042	.275**						
Daily Measures - Beginning of the Week															
7. Sleep	2.98	.99	1.00	6.00	.246**	.101	.217**	.354**	.211**	-.023					
8. Pre-sleep Rumination	2.56	1.41	.67	7.00	.268**	.073	.087	.178*	.346**	.069	.545**				
9. Stress	1.66	.77	.00	3.50	.220**	.288**	.375**	.072	.105	.135	.070	.215**			
Daily Measures - Midweek															
10. Sleep	2.96	0.99	1.00	6.25	.480**	.165*	.215**	.328**	.301**	.103	.292**	.333**	.180*		
11. Presleep Rumination	2.56	1.46	.67	7.00	.398**	.257**	.249**	.219**	.523**	.207**	.335**	.545**	.172*	.583**	
12. Stress	1.72	.78	.20	3.90	.180*	.508**	.526**	.155*	.233**	.275**	.188*	.090	.434**	.254**	.277**

Note: * $p < .05$. ** $p < .01$.
PSQI = Pittsburgh Sleep Quality Index; RRS-B = Ruminative Response Scale – Brooding subscale; PSS = Perceived Stress Scale. Higher sleep scores indicate worsened sleep quality.

Table 2 – Results from linear mixed-effects model analysis

			95% CI				
Sleep	Estimate	SE	Lower	Upper	df	t	*p*
Within-Person (Fixed Effects)							
Intercept	**11.29**	0.38	10.54	12.05	468.66	29.38	**< .001**
Pre-sleep Rumination	**0.45**	0.06	0.32	0.57	75.25	6.94	**< .001**
Stress	-0.02	0.02	-0.07	0.03	310.52	-0.83	0.409
Week Moment	0.12	0.15	-0.18	0.43	307.30	0.81	0.420
Pre-sleep Rumination × Stress	0.01	0.01	-0.02	0.03	398.68	0.67	0.502
Between-Person (Fixed Effects)							
RRS-B	0.02	0.10	-0.17	0.21	162.42	0.17	0.861
PSS	**0.13**	0.04	0.05	0.20	162.92	3.14	**0.002**
RRS-B × PSS	**0.03**	0.01	0.01	0.05	163.98	2.47	**0.014**
Random Effects							
σ^2	6.99	2.64					
$\tau 00$	4.78	2.19	1.81	2.54			
$\tau 11$	0.12	0.35	0.21	0.53			
ICC	0.44						
$\rho 01$	-0.04		-0.48	0.36			

Note: Nsample = 166; Nobservations = 498.
RRS-B = Ruminative Response Scale – Brooding subscale; PSS = Perceived Stress Scale. Daily variables (within-person variables) have been centered within clusters. Trait variables (between-person variables) have been grand mean-centered.
$\tau 00$ = between-person variability in sleep (random intercept); $\tau 11$ = between-person variability in the effect of pre-sleep rumination on sleep (random slope); σ^2 = residual variance; ICC = intra-class correlation; $\rho 01$ = correlation between the random intercept and the random slope of pre-sleep rumination.
Higher sleep scores indicate worsened sleep quality.

5. Discussion

The present study aimed to examine the relationship between rumination, stress, and SQ in women using a diary-based design. Specifically, we analyzed both trait-level brooding and daily pre-sleep rumination, as well as trait stress and daily stress, to capture both trait individual differences and day-to-day variations in these psychological processes.

At the daily level, the findings from multilevel modeling suggest that pre-sleep rumination is significantly associated with SQ. Consistent with previous evidence (Åkerstedt et al., 2012; Winzeler et al., 2014), on days when participants reported elevated levels of pre-sleep rumination relative to their weekly average, they experienced significantly poorer SQ that night. In contrast, daily stress was not significantly associated with SQ, nor did it interact significantly with pre-sleep rumination. In other words, when both variables were entered simultaneously as independent variables, pre-sleep rumination accounted for unique variance in SQ above and beyond perceived stress. Notably, correlational analysis revealed a consistent relationship between daily stress and same-day pre-sleep rumination, indicating that women experiencing higher stress during the day were more likely to engage in rumination at bedtime. Despite this co-occurrence, pre-sleep rumination appears to operate as an independent factor in shaping SQ, possibly by carrying over and incorporating the effects of daily stress, thereby overshadowing the direct association of daily stress with sleep outcomes. This interpretation aligns with the literature on pre-sleep cognitive arousal, defined as stress-related hyperactivation occurring around sleep onset (Espie, 2007; Harvey et al., 2005), which directly interferes with sleep initiation and compromises overall SQ. Accordingly, pre-sleep rumination may represent a more proximal mechanism through which daytime psychological burden translates into nocturnal sleep disruption, independently of the level of perceived stress reported during the day. However, some methodological considerations warrant caution in driving these conclusions. First, it is worth noting that the sparse sampling schedule may have constrained the reliability with which within-person variability has been estimated. Intraindividual fluctuations in perceived stress and rumination are known to operate across multiple timescales (Smyth et al., 2023), and three measurement occasions may provide insufficient granularity to model such dynamics adequately. Second, and more broadly, the correlational and observational nature of the study design precludes causal inference. Accordingly, the present findings should be interpreted as preliminary evidence and need replication through experimental or longitudinal designs with more intensive measurement protocols.

At the trait level, trait stress showed a significant association with poorer SQ, consistent with H3 and previous evidence (Lee et al., 2013). Notably, this finding contrasts with the null association between daily stress and SQ: Although daily stress exhibited significant fluctuations over the course of the week (increasing from the weekend to midweek), it showed no significant association with same-night SQ when modeled as a within-person deviation from each participant's weekly average. These results may indicate a relative stability and pervasiveness of trait stress as a psychological vulnerability factor compared with the more transient and context-dependent nature of daily stress. In other words, while women may experience temporary spikes in stress during the week, it is their trait, baseline levels of stress that appear to exhibit a more consistent and deleterious linkage with SQ. Day-to-day fluctuations in stress may be thus less prominent than stable, trait-like stress patterns. As trait stress progressively shapes daily experiences of stress, it may act as the primary driver of sleep disruptions, overshadowing transient day-to-day stress variations. However, given the correlational nature of the study, this conclusion remains tentative and warrants further investigation.

In contrast to expectations, brooding did not exhibit a significant direct linkage with SQ, providing only partial support for H3. Nonetheless, although brooding alone was not significantly associated with SQ in our model, its relationship with SQ became evident when interacting with trait stress. This result supports H4, indicating a combined association of brooding and trait stress with SQ. Specifically, women with average higher levels of trait stress experienced a stronger negative relationship between brooding and sleep. This finding adds nuance to the literature examining rumination as a maladaptive ER strategy associated with SQ (for a review, Clancy et al., 2020), with brooding rumination being particularly linked to sleep problems (Guastella & Moulds, 2007). Cross-sectional studies consistently show that both stress and rumination are detrimental for sleep outcomes. For instance, Tousignant et al. (2019) reported significant indirect effects of stress on SQ through pre-sleep arousal across both low and high levels of rumination. Similarly, other studies have identified rumination as a mediator of the association between stress and sleep (Berset et al., 2011; Du et al., 2020; Li et al., 2019; Liu & Cao, 2022; Matti et al., 2024; Thorsteinsson et al., 2019). Focusing on women, our findings build on this existing evidence by revealing that brooding is associated with poorer SQ among those women prone to experience heightened trait stress. Simple slopes analyses revealed that brooding was significantly associated with poorer SQ only at high levels of trait stress, thus indicating that women who are predisposed to stress are more vulnerable to brooding-related sleep disruptions.

Finally, the present results provide an important contribution to the gender-specific literature on sleep. Women are known to report higher levels of both trait rumination (for a meta-analysis, Johnson & Whisman, 2013), particularly in association with stress (García et al., 2017; Morrison & O'Connor, 2005; Zoccola & Dickerson, 2012), and are more vulnerable to stress-related disorders (Nolen-Hoeksema et al., 2008) and to impaired sleep (Fatima et al., 2016; Luca et al., 2015). Our findings extend this body of research suggesting that the negative association between brooding and SQ is not uniform across individuals, but it is rather intensified in women with high levels of trait stress. The observed interaction between brooding and trait stress points to a compounded vulnerability that may help explain the disproportionate prevalence of sleep disturbances among women, even when daily stress exposure is potentially comparable to that of men. Thus, our results underscore the importance for gender-sensitive approaches to understanding and addressing sleep patterns.

Although – to our knowledge – this is the first study to explore a possible link between pre-sleep rumination, daily stress, and SQ in a sample of women, several limitations must be acknowledged. First, due to statistical power constraints, we were unable to examine potential interaction effects between trait and daily variables. Future studies could investigate whether the relationship between pre-sleep rumination, daily stress, and SQ differs among high-trait ruminators or women with high trait stress.

Another limitation concerns the study design. We conducted three assessments only within a single week, and this reduced number of assessment points may have reduced statistical power to reliably detect within-person effects, thus limiting our ability to capture more nuanced day-to-day fluctuations. As a result, the stability of the observed within-person associations should be interpreted with caution. Future studies could include more frequent assessments over a longer period to better capture the temporal dynamics and variability in pre-sleep rumination, daily stress, and SQ.

Lastly, we did not include objective measures of SQ, relying solely on self-reported data. This choice is consistent with the ecological focus of the study design, in which both independent variables and outcomes were assessed using the same method. Importantly, SQ is a multidimensional construct that varies within individuals, and its overall evaluation partly depends on how individuals subjectively weigh its different components (Harvey et al., 2008). This reflects a well-established distinction between subjective and objective SQ, which do not always converge (Benz et al., 2023; Masaki et al., 2025). In this sense, self-reported SQ may capture psychologically meaningful aspects of the sleep experience that objective measures alone cannot fully reflect, and vice versa. At the same time, relying

exclusively on self-report measures may introduce common method variance, potentially inflating the observed associations among variables. Therefore, although this approach was aligned with the ecological focus of the study, the absence of objective indicators represents a limitation. Future research could aim to replicate our findings by incorporating both self-reported and objective measures, such as actigraphy or polysomnography. Combining these approaches could reveal potential discrepancies between perceived and actual SQ, further clarifying the mechanisms underlying sleep impairment.

Despite these limitations, the present study provides new evidence to understand the interplay between rumination, stress and SQ among women on a daily basis. Overall, our findings highlight the maladaptive association between pre-sleep rumination and sleep outcomes and suggest that women experiencing heightened stress are particularly vulnerable to the detrimental relationship of brooding with SQ. These results collectively highlight the importance of targeting both daily fluctuations and trait-level tendencies, potentially informing for future interventions aimed at improving sleep in women. From a practical perspective, these results suggest that interventions aimed at improving sleep should address both stress management, particularly in individuals with higher average trait stress, and the reduction of maladaptive rumination at bedtime.

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The Role of Rumination and Stress in Women's Sleep:
Evidence from a Diary Study
SUPPLEMENTAL MATERIAL

List of Content:

1. Method

1.1. Description of the Full Model Specification Procedure

We specified fixed effects for trait levels of stress and brooding rumination, as well as their interaction, to assess how these stable traits relate to SQ. Additionally, we included daily measures of stress and pre-sleep rumination, along with their interaction, to capture the effects of day-to-day fluctuations on SQ. We person-mean centered the daily variables to capture within-person effects, while trait stress and brooding rumination were grand mean-centered to better capture between-individuals differences (Enders & Tofighi, 2007; Paccagnella, 2006). We also included time as an additional predictor variable to account for temporal trends in the outcome.

Regarding random effects, we followed a systematic procedure to evaluate their inclusion in the model to account for non-systematic variations between individuals (where the individuals serve as the clustering variable). We fitted separate models for each random coefficient (i.e., pre-sleep rumination, daily stress), allowing both random intercepts and random slopes within individuals. This approach enabled each individual to have their own average daily sleep score and unique slopes for the effects of pre-sleep rumination and daily stress on sleep. For each model, we assessed the significance of random effects using the Likelihood Ratio Test (LRT) by comparing a full model, which included the random slope, to a simpler model with only a random intercept (Raudenbush & Bryk, 2002). If the LRT indicated that the random effect was not statistically significant, the random slope was omitted from the final model.

After the steps described, we also compared a model that included all random coefficients simultaneously to a more parsimonious model that retained only the statistically significant random coefficient(s) according to the LRT. Model comparisons were based on the Akaike Information Criterion (AIC; Akaike, 1973) and Bayesian Information Criterion (BIC; Schwarz, 2007) and served as further validation for our model selection process (Müller et al., 2013). This iterative approach ensured a parsimonious model while minimizing the risk of overfitting and convergence issues.

1.2. Attrition and Missing Data Handling

The compliance with the study was good overall. Four percent of the participants did not complete the baseline questionnaire. Concerning the daily assessments, 9.4% of the participants did not complete all the daily questionnaires. The overall sample sizes were thus as follows: Baseline

assessment N = 162; Saturday (weekend assessment) N = 147; Sunday (weekend assessment) N = 146; Monday (beginning of the week assessment) N = 148; Tuesday (beginning of the week assessment) N = 153; Wednesday (midweek assessment) N = 147; Thursday (midweek assessment) N = 152.

Missing data were handled using Expectation Maximization (EM) algorithm for imputation. In this process, the algorithm iteratively predicts missing values based on observed data, optimizing estimates by maximizing the likelihood function (Chiorri, 2023; Enders, 2022). The EM algorithm assumes that data are Missing At Random (MAR) and allows for unbiased estimates of both means and variances.

2. Results

2.1. Results From the Full Model Specification Procedure

The ICC coefficient was 0.47 for pre-sleep rumination, 0.25 for daily stress, and 0.32 for daily SQ. These values indicate that all three variables showed substantial variability across individuals (i.e., random intercept variance significantly greater than zero, ICC > 0.05), confirming the appropriateness of a multilevel approach.

When evaluating which random effects to include in the model, the Likelihood Ratio Test (LRT) showed that incorporating random slopes for daily stress did not significantly improve model fit compared to a simpler model that included only a random intercept for the clustering variable, $\chi^2(2) = 0.97$, $p = 0.613$. In contrast, the test revealed that including random slopes for daily pre-sleep rumination significantly enhanced model fit, $\chi^2(2) = 11.51$, $p = 0.003$.

Further comparison between the model including random slopes for both the within-level predictors (i.e., daily pre-sleep rumination and daily stress) and the model including random slope only for daily pre-sleep rumination showed no significant difference in fit, $\chi^2(3) = 1.68$, $p = 0.641$. The AIC and BIC values were lower for the model that included random slope only for daily rumination (AIC = 2622.7, BIC = 2673.2) compared to the model including random slopes for both the predictors (AIC = 2625.8, BIC = 2678.1). Notably, the model including random slope only for daily pre-sleep rumination achieved the best AIC and BIC values across all the models assessed. The LRT, AIC, and BIC results are reported in Table S1 and Table S2 in the supplementary materials. These findings suggested that the simpler model with random slope only for daily rumination provided a better fit for the data.

3. Tables

Table S1 - Models' comparison using AIC and BIC

Model	AIC	BIC
Random slopes only for pre-sleep rumination	2657.472	2707.999
Random slopes only for daily stress	2668.202	2718.729
Random slopes only for both pre-sleep rumination and daily stress	2661.561	2724.720
No random slopes	2665.350	2707.456

Note:

Model with random slopes only for pre-sleep rumination:

Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Pre-sleep Rumination | ID)

Model with random slopes only for daily stress:

Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Daily Stress | ID)

Model with random slopes for both pre-sleep rumination and daily stress:

Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Pre-sleep Rumination | ID) + (1 + Daily Stress | ID)

Model without random slopes:

Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment (1 | ID)

Nsample = 166; Nobservations = 498.

ID = clustering variable.

Daily variables (i.e., Pre-sleep Rumination, Daily Stress) have been centered within clusters. Trait variables (i.e., Brooding, Trait Stress) have been grand mean-centered.

Table S2 - Models' comparison using AIC, BIC, and LRT

Models' comparison	*AIC*	*BIC*	χ^2	*df*	*p*
Random slopes only for pre-sleep rumination	2622.7	2673.2			
Random slopes for both pre-sleep rumination and daily stress	2627.0	2690.1	1.68	3	0.641
Random slopes only for daily stress	2633.2	2683.7			
Random slopes for both pre-sleep rumination and daily stress	2627.0	2690.1	12.21	3	0.007
Random slopes only for pre-sleep rumination	2622.7	2673.2			
Random slopes only for daily stress	2633.2	2683.7	0.00	0	-
No random slopes	2630.2	2672.3			
Random slopes only for daily stress	2633.2	2683.7	0.98	2	0.613
No random slopes	2630.2	2672.3			
Random slopes only for pre-sleep rumination	2622.7	2673.2	11.51	2	0.003
No random slopes	2630.2	2672.3			
Random slopes for both pre-sleep rumination and daily stress	2627.0	2690.1	13.19	5	0.022

Note:
Model with random slopes only for pre-sleep rumination:
Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Pre-sleep Rumination | ID)
Model with random slopes only for daily stress:
Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Daily Stress | ID)
Model with random slopes for both pre-sleep rumination and daily stress:
Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment + (1 + Pre-sleep Rumination | ID) + (1 + Daily Stress | ID)
Model without random slopes:
Sleep ~ 1 + Pre-sleep Rumination + Daily Stress + Pre-sleep Rumination * Daily Stress + Brooding + Trait Stress + Brooding * Trait Stress + Week Moment (1 | ID)
Nsample = 166; Nobservations = 498.
ID = clustering variable.
Daily variables (i.e., Pre-sleep Rumination, Daily Stress) have been centered within clusters. Trait variables (i.e., Brooding, Trait Stress) have been grand mean-centered.

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