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Loneliness, sleep and daily stress: Evidence of direct and indirect effects

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Abstract

This study investigated: i) the effects of loneliness on self-reported sleep outcomes and daily stress/hassles, ii) whether the effects of loneliness on sleep outcomes were mediated through prior-day stress/hassles and iii) if the effects of loneliness on daily stress/hassles were mediated through prior-night sleep measures. Using a 7-day diary design, this study aimed to investigate relationships between loneliness, daily sleep outcomes and daily stress/hassles. Participants ($N = 174$, M_{age} 19.95, 86.2% female) completed the UCLA Loneliness Scale once before a 7-day online diary twice per day. Measures of daily stress and hassles were completed before bed and sleep outcomes the following day. Multilevel modelling found higher levels of loneliness were associated with poorer sleep quality, greater pre-sleep arousal, morning tiredness, fewer total hours slept and higher levels of daily stress and hassles across the 7-day study. Loneliness was found also to have indirect effects on sleep quality, pre-sleep arousal and morning tiredness through prior-day daily stress and hassles. In addition, loneliness also had indirect effects on daily stress and hassles through prior night sleep measures. The current findings suggest that interventions aimed at mitigating the effects of loneliness should also incorporate components that target modifiable risk factors such as sleep and stress.

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KEYWORDS

daytime functioning, lonely, sleep quality, social isolation, stress

INTRODUCTION

Loneliness is an important yet neglected social determinant of mental and physical health (WHO, 2024). Recent prevalence estimates have suggested that problematic levels of loneliness are experienced by large proportions of populations worldwide with rates as high as 24% in some countries (Surkalim et al., 2022). It is now well-established that loneliness is associated with poor mental and physical health (Hawkley & Cacioppo, 2010; Holt-Lunstad, 2022; Holt-Lunstad et al., 2015; Park et al., 2020; Steptoe, 2023; Valtorta et al., 2016). For example, loneliness has been found to be associated with increased cardiovascular disease outcomes (Brown et al., 2018; Liang et al., 2023), stroke (Valtorta et al., 2016), chronic health conditions (Barlow et al., 2015), inflammation (Moieni et al., 2015), major depressive and generalised anxiety disorders (Domenech-Abella et al., 2020), the onset of new mental health problems (Mann et al., 2022) and has received a great deal of research attention during the coronavirus disease 2019 pandemic (Ernst et al., 2022; O'Connor et al., 2023; Wilding et al., 2022).

Alarmingly, Holt-Lunstad et al. (2015), in large meta-analytic review, found that loneliness resulted in a 26% increased likelihood of mortality. As a result, loneliness has been identified as a serious global health issue. The United Nations has deemed it a major focus for its Decade of Healthy Ageing (2021–2030) (United Nations, 2020), the United States (US) Office of the Surgeon General (2023) has published a call to action on the epidemic of loneliness and isolation and numerous countries have appointed Ministers for Loneliness to implement policies to urgently mitigate its effects (Steptoe, 2023).

It has been proposed that loneliness is best conceptualised from an evolutionary perspective, such that being a member of a social group provides individuals with a safe and secure environment to survive and thrive, while the perception of being socially isolated or lonely will give rise to feelings of threat and vulnerability (Cacioppo et al., 2006). Moreover, it is argued that perceptions of loneliness will trigger implicit hypervigilance for social threats that will influence a range of psychological, physiological and behavioural processes ultimately increasing morbidity and mortality.

One of the key mechanisms linking loneliness to negative physical and mental health outcomes is sleep disturbance and, in particular, impaired sleep quality. It is theorised that the unsafe feeling triggered by loneliness and the need to remain vigilant is antithetical to having restful, restorative sleep. There is now good evidence that loneliness is associated with sleep outcomes and a recent systematic review and meta-analysis found that loneliness is correlated with self-reported sleep disturbance but not total sleep duration (Griffin et al., 2020). However, it is worth noting that of the 27 studies included in this review, only 8 adopted a longitudinal design and none included a daily diary design. Another larger systematic review and meta-analysis that synthesised loneliness and sleep studies, and included insomnia outcomes, also found robust evidence for an association between more severe sleep problems and perceptions of loneliness (Hom et al., 2020). Nevertheless, again it is worth noting that of 110 unique samples included in this review, 99.1% were cross-sectional and (separately) only 7.3% reported longitudinal findings. Therefore, one of the aims of the current study was to investigate the

extent to which the effects of loneliness on sleep outcomes are observable daily in more naturalistic, ecologically valid settings. A strength of using a daily diary approach is that it allows for the sampling of variables of interest over an extended period of time, over more and less stressful days and allows for each participant to act as their own control.

Despite the growing evidence base relating loneliness to sleep outcomes and recent work indicating that sleep disturbance mediates the association between loneliness and health (e.g., Griffin et al., 2021), less is known about the precise mechanisms that may link loneliness to sleep disturbance. Cacioppo et al.'s (2006) loneliness model hypothesises that lonely individuals, relative to nonlonely individuals, will perceive the world as more threatening. Therefore, as a result, it is likely that lonely individuals will also experience greater levels of perceived stress and more hassles on a day-to-day basis, which may then influence subsequent sleep quality and daytime functioning. In other words, it is also possible that loneliness may have adverse effects on sleep disturbance indirectly by influencing same-day stress levels. However, the opposite may also be true for the daily stress-sleep disturbance part of this relationship, such that loneliness may also have adverse effects on daily stress levels indirectly through influencing prior-night sleep disturbances. Bi-directional relationships between stress and sleep outcomes have been reported in a growing number of studies (e.g., O'Connor et al., 2024; Slavish et al., 2021; Yap et al., 2020). A study by Yap et al. (2020), using an intensive longitudinal design, found clear bi-directional relations between stress and sleep outcomes, such that prior-day stress influenced sleep that evening, and that worse sleep outcomes predicted higher next-day stress. Similarly, Slavish et al. (2021) also found evidence that daily stress and sleep disturbances occurred in a bidirectional fashion using a range of measures. A recent study by O'Connor et al. (2024), found that childhood trauma indirectly influenced sleep quality and morning tiredness through higher levels of prior-day stress, rumination and worry. This study also found that the relationship between daily stress and sleep quality acted in a bi-directional fashion such that childhood trauma also had indirect effects on daily stress through the previous night's sleep quality. Therefore, in the current study, we wanted to test both of these indirect pathways, thereby examining: 1) whether the effects of loneliness on sleep outcomes were mediated through prior-day stress and hassles, and 2) whether the effects of loneliness on daily stress and hassles were mediated through prior-night sleep measures.

Finally, there is good evidence that ageing is associated with higher rates of loneliness and greater sleep disturbance and reductions in physical health. Older adults appear to be more vulnerable to the negative effects of loneliness in terms of health outcomes (e.g., Griffin et al., 2021; Hawkley et al., 2006; Hawkley & Kocherginsky, 2018; Shankar et al., 2017). However, a large number of previous studies that have explored associations between loneliness and sleep disturbance have been conducted in adults and older adults. For example, only 20% of findings included in a recent large meta-analysis were conducted in young adults (Hom et al., 2020). Approximately 70% of studies have focused on middle-aged and older adults. As a result, many of these investigations cannot rule out reverse causality, such that, individuals with impaired health status, which increases with age, self-report higher levels of loneliness due to their reduced health status limiting their social contacts. Determining the mechanisms by which loneliness is associated with sleep disturbance in young adults, *prior* to the development of mental and physical health problems may help further elucidate the pathways linking loneliness, sleep and adverse health outcomes and may uncover key targets for intervention. In other words, the current study was interested in investigating the effects of loneliness in young and healthy adults.

Therefore, in summary, using a 7-day daily diary design, the current study aimed to 1) investigate the effects of loneliness on self-reported sleep outcomes, daily stress and hassles in a sample of young and healthy adults, 2) to test whether the effects of loneliness on sleep outcomes were mediated through prior-day stress and hassles and 3) whether the effects of loneliness on next-day daily stress and hassles were mediated through prior-night sleep measures. The following hypotheses were tested:

H1. Higher levels of loneliness will be associated with poorer daily sleep quality, greater sleep onset latency, pre-sleep arousal, morning tiredness, fewer total hours slept and higher levels of daily perceived stress and hassles.

H2. There will be indirect effects of loneliness on daily sleep measures via prior-day perceived stress and hassles.

H3. There will be indirect effects of loneliness on daily perceived stress and hassles via prior-night sleep measures.

METHOD

Design and participants

Healthy participants were recruited for a study exploring life experiences, stress and wellbeing. This study was conducted entirely remotely in the United Kingdom and employed an interval contingent daily diary design whereby participants completed an online daily diary before going to bed (to assess daily stress and hassles from each day) and again the following day at noon (to assess sleep measures last night). Background questionnaire measures were completed online at the beginning of the study. Participants were recruited using the university's participant pool scheme, through advertisements via social media, online posters and word of mouth. Inclusion criteria required participants to be aged between 18 and 30 years old, fluent in English and to be without a long-term health condition or a chronic illness. These criteria were used to prevent potential confounding influences of age-related decline or extreme values from sleep or long-term health conditions impacting the measures administered. The sample size was determined using a summary-statistics-based power analysis (Murayama et al., 2022) to detect a cross-level effect. The approach allows you to estimate the sample size for cross-level effects by inputting data based on prior work or pilot data. In the current study, we used data from another study (Rogerson et al., 2024) to calculate a cross-level effect of loneliness on a similar sleep outcome (which yielded the following coefficient; $t = -4.51$, $df = 207$). The power analysis showed that a minimum sample of 125 was required to achieve 80% power to detect. Therefore, to account for attrition, drop out and missing days, the study aimed to recruit around 200 participants. Participants had to have completed at least 2 days of diary data to be included in the analyses. Two hundred and two students provided informed consent and were recruited to the study, eight participants were excluded as they were aged over 30 years, and twenty were excluded for completing less than 2 days of diary data. As a result, 174 participants were included in the main analyses. The study was approved by the University Department's Research Ethics Committee (PSYC-692).

Measures

Background questionnaire

The background questionnaire included questions on age, sex, height, weight (to calculate body mass index, BMI), employment status, long-term health conditions and whether participants were married or living with a partner.

Loneliness

Loneliness was measured using the UCLA three-item loneliness scale (Hughes et al., 2004). This scale has been shown to have good reliability and validity (Hughes et al., 2004). Participants were asked to respond about their experiences on a three-point scale (hardly ever, some of the time, often). Scores ranged from 3 to 9 where a higher score indicates greater loneliness. Cronbach's alpha for the scale in the current sample was 0.85.

Midday daily diary questionnaires

Sleep measures

Participants reported how many hours they had slept the night before (total sleep), how long it took them to fall asleep last night (sleep onset latency, SOL), how tired they felt this morning (1 = not at all extending to 5 = very tired) and a measure of sleep quality ("Last night, how would you rate your sleep quality overall?"; 1 = 'very bad' to 7 = 'very good'). The sleep outcome measures were informed by the Consensus Sleep Diary (Carney et al., 2012) and the Pittsburgh Sleep Quality Index (Buysse et al., 1989) and have been shown to have good reliability and validity (e.g., Carney et al., 2012). Note that the current study was concerned with identifying relationships between loneliness and indicators of potential sleep disruption (e.g., sleep quality, sleep onset latency, total hours slept etc.) as this may best help inform more precise sleep hygiene interventions in the future, the current analyses focussed on the individual sleep outcomes.

Pre-sleep arousal was also assessed using two items modified from the Pre-Sleep Arousal Scale (Nicassio et al., 1985). These included "As you were trying to go to sleep last night, did thoughts keep running through your mind?" and "As you were trying to go to sleep last night, did you experience a jittery, nervous feeling in your body?" These items were rated on a scale that extended from 1 = 'not at all' to 10 = 'very much so'. These two items have been successfully utilised elsewhere (Russell et al., 2016; Tang et al., 2012). The between-person and within-person Omega values were $\omega = 0.85, 0.78$, respectively.

Evening daily diary questionnaires

Perceived stress was measured using a singular item asking participants "How stressed have you felt today?". This item was rated from '0 – not at all stressed' to '4 – extremely stressed'. This item was developed by the research team for the purpose of the current study based on standard single-item assessments of stress and has good face validity (O'Connor & Ferguson, 2016).

Daily Hassles were measured using the adapted Hassles and Uplifts Scale (DeLongis et al., 1988) as used by Tinajero et al. (2020). Six categories were chosen which participants

rated on a Likert scale from '0 – none or not applicable' to '3 – a great deal'. For daily hassles, the questions asked 'Today, how much of a hassle were ___ for you?' and the categories were friends, work/school, external events, physical health, romantic partner and co-workers. The mean across all categories was taken for each day to indicate the degree of daily hassles. The between-person and within-person Omega values were $\omega = 0.81, 0.48$, respectively. Note that daily uplifts were also measured in the study, however, both reliability coefficients were low, therefore, we decided to exclude this variable from the analyses.

Data analysis

Participants completed 77% of their midday diaries (942 from a maximum of 1,218) and 84% of their evening diaries (1,022 from a maximum of 1,218). There were no missing data within days (i.e., within a day, the electronic diary required participants to answer each of the brief questions). The data were analysed using multilevel modelling (HLM 7, Raudenbush et al., 2011). The datasets were lagged such that daily stress levels preceded the daily sleep outcomes in one dataset and sleep preceded daily stress levels in a second dataset (i.e., given missing days, we ensured that the correct sleep day outcome was preceded by the correct stress day scores and vice a versa). The data were considered to have a two-level hierarchical structure. The Level 1 variables (perceived stress, hassles and daily sleep outcomes) were group mean-centred (i.e., centred at individual level) and modelled as random effects as we assumed that each of the within-person variables would vary from day to day. The Level 2 dichotomous variable (relationship status) was uncentered and Level 2 continuous variables were grand mean-centred (loneliness, age, BMI). The effects of Level 2 variables were assumed to be fixed. The main analyses tested whether loneliness had cross-level (main) effects on daily sleep outcomes, perceived stress and hassles. Age, BMI and relationship status were entered as control variables given these variables have been found previously to covary with sleep outcomes and loneliness (e.g., Griffin et al., 2021; Tinajero et al., 2020). We also followed the recommendations put forward by Simmons et al. (2011) in terms of transparency regarding the treatment of covariates and we present the main models first without any covariates and then with the covariates. Multilevel mediation using the MLmed computational macro for SPSS was used to test whether there were: i) indirect effects of loneliness on sleep outcomes via prior-day stress/hassles and ii) indirect effects of loneliness on daily stress/hassles via prior-night sleep outcomes (Hayes & Rockwood, 2020; Rockwood, 2017). Note that given the absence of effects of the control variables (age, BMI and relationship status) in the main analyses, these variables were not entered in the multilevel mediation analyses. In addition, in all analyses, to account for multiple comparisons, we adopted a more conservative significance level ($p < 0.01$).

The general form for the full HLM model was:

$$\begin{aligned}\text{Level 1 outcome} = {} & \beta_{00+}\,\beta_{01}{}^{*}(\text{AGE}) + \beta_{02}{}^{*}(\text{BMI}) + \beta_{03}{}^{*}(\text{RELATIONSTATUS}) \\ & + \beta_{04}{}^{*}(\text{LONELINESS}) + r_0 + e\end{aligned}$$

Note: Level 1 outcome = the within-person variation in each daily measure, r_0 is the random intercept, e = residual error term.

RESULTS

Participants were aged between 18 and 30 years of age ($M = 19.95$ years, SD = 1.73 years; 97.1% were not married or living with a partner). The sample consisted of 150 (86.2%) females. Descriptive statistics for the main study variables are presented in Table 1. Inspection of these data shows that mean levels of loneliness are similar to other recent studies (e.g., O'Connor et al., 2023).

Effects of loneliness on sleep and stress measures over 7 days

The findings for each of the models are presented in Table 2. The results showed there were significant main effects of loneliness on sleep quality, morning tiredness, total hours slept and pre-sleep arousal. In addition, significant main effects of loneliness on perceived stress and daily hassles. The findings indicated that higher levels of loneliness were associated with poorer sleep quality, greater pre-sleep arousal, morning tiredness and fewer total hours slept and higher levels of daily perceived stress and daily hassles across the 7-day study period.

Indirect effects of loneliness on daily sleep measures through prior-day stress and hassles

Next, we tested whether there were indirect effects of loneliness on daily sleep measures via prior-day stress and hassles. In these analyses, loneliness score (at Level 2) and sleep measures (at Level 1) were the X and Y variables, respectively, and daily stress and hassles (at Level 1) acted as the mediators (M variable) in separate analyses. The analysis showed that there were indirect effects of loneliness on sleep quality (estimate = −0.049, 95% CI [−0.088, −0.018]),

TABLE 1 Descriptive statistics for daily (level 1) and between-person (level 2) measures across 7 days.

Variables	Mean	SD
Level 1		
Sleep quality	4.63	1.43
Morning tiredness	2.64	1.15
Sleep onset latency (mins)	30.25	41.22
Total hours slept (mins)	456.99	91.44
Pre-sleep arousal	6.79	4.55
Daily perceived stress	1.17	1.02
Daily hassles	5.22	3.08
Level 2		
Age	19.95	1.72
Sex (% female)	86.20	--
Body mass index	22.54	4.18
Loneliness	4.94	1.74

TABLE 2 Effects of loneliness on sleep-related variables and daily stress and hassles across 7 days.

	Unadjusted				Adjusted for covariates			
		Coeff	SE	*p* value		Coeff	SE	*p* value
Sleep quality								
Intercept	β_{00}	4.629	0.064	<0.001	β_{00}	4.630	0.064	<0.001
Loneliness	β_{01}	−0.271	0.066	<0.001	β_{01}	−0.264	0.065	<0.001
Age	β_{02}	--	--	--	β_{02}	−0.002	0.168	0.989
BMI	β_{03}	--	--	--	β_{03}	0.057	0.046	0.220
Relationship status	β_{04}	--	--	--	β_{04}	−0.094	0.106	0.374
Tiredness								
Intercept	β_{00}	2.642	0.056	<0.001	β_{00}	2.641	0.056	<0.001
Loneliness	β_{01}	0.145	0.054	0.008	β_{01}	0.143	0.054	0.010
Age	β_{02}	--	--	--	β_{02}	−0.166	0.139	0.233
BMI	β_{03}	--	--	--	β_{03}	0.009	0.043	0.819
Relationship status	β_{04}	--	--	--	β_{04}	0.083	0.073	0.251
Sleep onset latency								
Intercept	β_{00}	31.196	2.731	<0.001	β_{00}	31.186	2.726	<0.001
Loneliness	β_{01}	1.764	1.936	0.363	β_{01}	1.539	1.988	0.440
Age	β_{02}	--	--	--	β_{02}	−1.241	5.583	0.824
BMI	β_{03}	--	--	--	β_{03}	−1.292	1.051	0.220
Relationship status	β_{04}	--	--	--	β_{04}	2.886	2.089	0.169
Total hours slept								
Intercept	β_{00}	456.241	4.183	<0.001	β_{00}	456.223	4.104	<0.001
Loneliness	β_{01}	−13.855	4.232	<0.001	β_{01}	−12.948	4.056	0.002
Age	β_{02}	--	--	--	β_{02}	−18.124	11.300	0.111
BMI	β_{03}	--	--	--	β_{03}	3.203	2.955	0.280
Relationship status	β_{04}	--	--	--	β_{04}	−13.917	6.090	0.024
Pre-sleep arousal								
Intercept	β_{00}	6.799	0.228	<0.001	β_{00}	6.795	0.226	<0.001
Loneliness	β_{01}	1.399	0.233	<0.001	β_{01}	1.389	0.230	<0.001
Age	β_{02}	--	--	--	β_{02}	−0.383	0.569	0.502
BMI	β_{03}	--	--	--	β_{03}	−0.314	0.178	0.080
Relationship status	β_{04}	--	--	--	β_{04}	−0.204	0.391	0.602
Perceived stress								
Intercept	β_{00}	1.197	0.049	<0.001	β_{00}	1.198	0.049	<0.001
Loneliness	β_{01}	0.205	0.059	<0.001	β_{01}	0.204	0.058	<0.001
Age	β_{02}	--	--	--	β_{02}	0.194	0.146	0.185
BMI	β_{03}	--	--	--	β_{03}	−0.007	0.041	0.856
Relationship status	β_{04}	--	--	--	β_{04}	0.009	0.062	0.876

(Continues)

TABLE 2 (Continued)

		Unadjusted			Adjusted for covariates			
		Coeff	SE	*p* value		Coeff	SE	*p* value
Daily hassles								
Intercept	β_{00}	2.956	0.137	<0.001	β_{00}	2.957	0.137	<0.001
Loneliness	β_{01}	0.523	0.159	0.001	β_{01}	0.522	0.158	0.001
Age	β_{02}	--	--	--	β_{02}	−0.001	0.374	0.997
BMI	β_{03}	--	--	--	β_{03}	−0.071	0.117	0.544
Relationship status	β_{04}	--	--	--	β_{04}	−0.071	0.107	0.507

morning tiredness (estimate = 0.045, 95% CI [0.017, 0.080]) and pre-sleep arousal (estimate = 0.243, 95% CI [0.097, 0.404]) through daily perceived stress. There was also an indirect effect of loneliness on pre-sleep arousal (estimate = 0.186, 95% CI [0.057, 0.333]) through daily hassles. These results show that higher levels of loneliness were associated with higher levels of daily stress that in turn were associated with poorer sleep that evening (see Table 3).

Indirect effects of loneliness on daily stress and hassles through prior-night sleep measures

We also tested whether there were indirect effects of loneliness on daily stress and hassles via prior-night sleep measures. In these analyses, loneliness score (at Level 2) and daily stress and hassles (at Level 1) were the X and Y variables, respectively, and sleep outcomes (at Level 1) acted as the mediators (M variable) in separate analyses. The results found that there were indirect effects of loneliness on daily stress levels through sleep quality (estimate = 0.039, CI [0.015, 0.068]) and pre-sleep arousal (estimate = 0.087, CI [0.051, 0.127]). Similarly, the analyses also found there were indirect effects of loneliness on daily hassles through sleep quality (estimate = 0.090, CI [0.034, 0.163]) and pre-sleep arousal (estimate = 0.195, CI [0.109, 0.292]). Taken together, these results showed that higher levels of loneliness were also associated with poor sleep quality and greater pre-sleep arousal that in turn were associated with higher perceived daily stress levels and a greater number of daily hassles the following day (see Table 4).

DISCUSSION

Several important results emerged from the current study. First, loneliness was found to be associated with a range of indicators of sleep disturbance in daily, naturalistic settings while controlling for relationship status, age and BMI. Second, loneliness was also found to be related to higher daily stress and a greater number of daily hassles. Third, loneliness also had indirect effects on sleep quality by influencing prior-day stress and hassles. Fourth, loneliness had indirect effects on daily stress/hassles through prior-night sleep measures.

The current study found that loneliness was associated with fewer total hours slept as well as poorer sleep quality, greater morning tiredness and pre-sleep arousal. The former result is

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TABLE 3 Indirect effects of loneliness on daily sleep measures through prior-day stress and hassles (mediators).

	Effect	SE	*t*/*Z*	*p*	95% CI
Stress - sleep quality					
Direct effect	−0.073	0.039	−1.828	0.069	−0.151, 0.006
Indirect effect	−0.049	0.017	−2.750	0.006	−0.088, −0.018
Stress - tiredness					
Direct effect	0.043	0.036	1.209	0.228	−0.027, 0.114
Indirect effect	0.045	0.016	2.794	0.005	0.017, 0.080
Stress - SOL					
Direct effect	1.031	1.874	0.583	0.583	−2.670, 4.731
Indirect effect	0.214	0.487	0.439	0.660	−0.736, 1.199
Stress – total hours					
Direct effect	−6.432	2.756	−2.333	0.021	−11.879, −0.985
Indirect effect	−1.067	0.802	−1.379	0.168	−2.909, 0.247
Stress – pre-sleep A					
Direct effect	0.443	0.128	3.469	0.001	0.191, 0.694
Indirect effect	0.243	0.078	3.106	0.002	0.097, 0.404
Hassles – sleep quality					
Direct effect	−0.086	0.039	−2.170	0.031	−0.164, −0.008
Indirect effect	−0.037	0.015	−2.357	0.018	−0.072, −0.010
Hassles - tiredness					
Direct effect	0.053	0.035	1.487	0.139	−0.017, 0.123
Indirect effect	0.037	0.015	2.464	0.013	0.011, 0.069
Hassles - SOL					
Direct effect	1.327	1.853	0.716	0.475	−2.332, 4.986
Indirect effect	−0.059	0.407	−0.146	0.884	−0.918, 0.753
Hassles – total hours					
Direct effect	−6.759	2.734	−2.472	0.014	−12.160, −1.358
Indirect effect	−0.803	0.687	−1.168	0.242	−2.384, 0.035
Hassles – pre-sleep A					
Direct effect	0.506	0.129	3.906	0.001	0.250, 0.762
Indirect effect	0.186	0.070	2.647	0.008	0.057, 0.333

Note: SOL = sleep onset latency; pre-sleep A = pre-sleep arousal.

contrary to the recent meta-analysis by Griffin et al. (2020) and a key study by Hawkley et al. (2010) that found that loneliness impairs daytime functioning but not sleep duration. Nevertheless, it is worth noting that the absence of an association with total hours slept in the Griffin et al. (2020) review was based on only four studies. Therefore, the current findings suggest that sleep duration, as well as poorer sleep quality, is likely to play a role in explaining the loneliness–health relationship.

TABLE 4 Indirect effects of loneliness on daily stress and hassles through prior-night sleep measures (mediators).

	Effect	SE	*t*/*Z*	*p*	95% CI
Sleep quality - stress					
Direct effect	0.059	0.029	2.033	0.044	0.002, 0.118
Indirect effect	0.039	0.013	2.870	0.004	0.015, 0.068
Tiredness - stress					
Direct effect	0.073	0.028	2.579	0.011	0.017, 0.129
Indirect effect	0.026	0.013	1.968	0.049	0.002, 0.053
SOL - stress					
Direct effect	0.100	0.031	3.263	0.001	0.039, 0.161
Indirect effect	0.002	0.003	0.060	0.952	−0.005, 0.006
Total hours - stress					
Direct effect	0.085	0.031	2.750	0.006	0.024, 0.146
Indirect effect	0.015	0.008	1.756	0.079	0.002, 0.035
Pre-sleep A - stress					
Direct effect	0.013	0.028	0.468	0.640	−0.043, 0.069
Indirect effect	0.087	0.019	4.506	0.001	0.051, 0.127
Sleep quality – hassles					
Direct effect	0.198	0.078	2.529	0.012	0.043, 0.352
Indirect effect	0.090	0.033	2.742	0.006	0.034, 0.163
Tiredness- hassles					
Direct effect	0.216	0.074	2.907	0.004	0.069, 0.363
Indirect effect	0.068	0.034	1.972	0.048	0.004, 0.140
SOL - hassles					
Direct effect	0.294	0.081	3.646	0.004	0.135, 0.434
Indirect effect	−0.003	0.007	−0.041	0.967	−0.016, 0.014
Total hours - hassles					
Direct effect	0.258	0.081	3.176	0.002	0.098, 0.419
Indirect effect	0.034	0.021	1.611	0.107	0.001, 0.085
Pre-sleep A - hassles					
Direct effect	0.092	0.078	1.164	0.246	−0.064, 0.247
Indirect effect	0.195	0.047	4.146	0.001	0.109, 0.292

Note: SOL = sleep onset latency; pre-sleep A = pre-sleep arousal.

Loneliness was also found to be associated with higher levels of daily perceived stress and a greater number of daily hassles. These are important findings that are consistent with Cacioppo et al. (2006)'s loneliness model which posits that loneliness places individuals in a heightened state of vigilance for potential threats in the environment. Moreover, our findings also show that loneliness influences not only the perceptions of daily stress levels but also the number of daily hassles. This is consistent with early work by Hawkley et al. (2003) and recent research by

Laustsen et al. (2024). In the latter case, using a longitudinal design, these authors found robust evidence that loneliness predicted an increase in the level of perceived stress four years later but also the converse was true, that changes in perceived stress predicted loneliness four years later. An important next step for researchers is to understand further the underlying mechanisms linking loneliness to appraisals of stress. For example, what is the precise role played by coping appraisals or access to social relationships. Nevertheless, these findings are concerning given the well-established effects of stress on hypothalamic–pituitary–adrenal axis regulation and cortisol dynamics, the autonomic nervous system, gene expression and chronic health outcomes (O'Connor, Branley-Bell, et al., 2021, O'Connor, Thayer, & Vedhara, 2021).

The current study also found novel evidence of several indirect effects of loneliness. The results of the multilevel mediation analyses showed that loneliness was associated with poorer sleep quality, greater pre-sleep arousal and morning tiredness levels on days preceded by higher daily perceived stress and hassles (for pre-sleep arousal only, in the latter case). The opposite was also found to be true whereby loneliness was related to higher daily stress and hassles on days following poorer sleep quality and pre-sleep arousal. These findings are consistent with other work (e.g., O'Connor et al., 2024; Slavish et al., 2021; Yap et al., 2020) that has shown that the relationship between daily sleep outcomes and daily stressors may operate in a bidirectional fashion. However, it is important that these precise findings are replicated using more sophisticated analyses in a larger sample before firm conclusions can be drawn. Nevertheless, these are notable findings as they suggest that in addition to having direct effects, loneliness may have damaging effects on health by: (i) adversely influencing sleep quality—an important component of sleep health (Buysse, 2014) and, ii) by contributing to increasing daily perceived stress levels and hassles and iii) by adversely influencing the relationships between each of these sets of variables. Overall, these findings add to the broader literature and indicate that the pathways through which loneliness influences mental and physical health are nuanced and not straightforward.

The findings that loneliness is robustly associated with different indicators of sleep disruption are consistent with a growing body of research (Griffin et al., 2020; Hom et al., 2020) and are in keeping with the notion that sleep disruption may be a key mechanism explaining the relationship between loneliness and health status (Griffin et al., 2021). However, these results are also noteworthy as they demonstrate clear evidence that loneliness is associated with sleep disruption in young healthy adults prior to potentially developing adverse mental and physical health outcomes as they get older. Moreover, they help rule out reverse causality as a potential explanatory factor, whereby, the observed relationships in the literature are explained by individuals with impaired health status reporting higher levels of loneliness due to age-related reductions in health status limiting their social contacts.

The results of the current study suggest that interventions aimed at reducing the adverse effects of loneliness should incorporate components that target modifiable risk factors such as stress, hassles, sleep quality and pre-sleep arousal, as well as interventions that attempt to enhance social connectedness. There is a growing body of research investigating the effectiveness of loneliness interventions that utilise a range of approaches including one-to-one, group level and large-scale initiatives (e.g., Cacioppo et al., 2015; Eccles & Qualter, 2021). However, the evidence base is mixed and there is a need to improve the scientific quality of these trials (Steptoe, 2023). The current results highlight the need to also target stress and components of sleep. There are promising new interventions such as acceptance and commitment-based approaches that may yield benefits for managing stress and hassles (e.g. Prudenzi et al., 2021). A large number of psychological interventions have been developed to help improve sleep

outcomes (e.g. Murawski et al., 2018; Saruhanjan et al., 2021). Of note are cognitive-behavioural-based sleep interventions that have been shown to improve sleep and also have beneficial effects on mental health outcomes in adults and adolescents (Blake & Allen, 2020; Blake et al., 2017). Future research should test the effectiveness of combined interventions aimed at reducing loneliness, stress and sleep disturbance.

We recognise the current investigation has limitations. We acknowledge that our sleep outcomes are self-reported and do not include objective measures, such as accelerometry or polysomnography and that data collection only lasted for 7 days. Future research should endeavour to include these techniques and collect data over longer periods separated by different assessment bouts over time (e.g., Jones et al., 2024); however, it is worth noting that key measures of sleep health are subjective (e.g., sleep quality, sleep satisfaction) and they have been captured in this study. Moreover, it may be fruitful to also consider exploring the relationships between loneliness and global assessments of sleep (by creating a latent factor of sleep health) in order to establish whether these relationships are observable at a global level as well as at the lower sleep indicator level. We are also cognizant that our assessment of perceived stress was a single-item measure, and that such measures have been criticised in relation to concerns around measurement error. However, recent theorising has challenged this view and has made robust arguments in relation to the use of single-item measures given their face, criterion, predictive and concurrent validity (see Allen et al., 2022). Nevertheless, it would be useful for future research, where possible, to include multi-item measures of perceived stress. We also note that the daily hassles measure had a between-person Omega coefficient that met acceptable conventions while the within-person coefficient was lower than acceptable conventions. Therefore, we should exercise some caution around interpreting the findings relating to daily hassles. Nevertheless, this observation raises an interesting issue about the extent to which a measure with six different categories may not always yield a high alpha, and it may be preferable for future research to use open-ended, free-response approaches to measure daily hassles (as well as including uplifts) (cf., Moss et al., 2024; O'Connor et al., 2008; O'Connor & Ferguson, 2016). We acknowledge also that the current sample was a predominantly female, student sample and therefore, may not be representative of a general healthy population. Moreover, as a result, the current findings may not reflect a true understanding of the range of human behavioural processes in the context of loneliness, stress and sleep. Future research should endeavour to recruit more representative and diverse samples. We also note that the UCLA 3-item loneliness scale was only administered once and it does not measure the emotional aspects of loneliness and, therefore, it would be important to replicate the current findings with a more comprehensive assessment of loneliness and to measure loneliness on multiple occasions to allow for dynamic relationships between loneliness, stress and sleep to be investigated. Finally, we did not have a detailed measure of social isolation (over and above relationship status) and recent research has highlighted the importance of assessing social network size as well as loneliness (e.g., Gallagher et al., 2024).

In conclusion, loneliness was found to be associated with poorer sleep quality, greater pre-sleep arousal, morning tiredness, fewer total hours slept and higher levels of daily perceived stress and hassles. It was found also to have indirect effects on sleep quality, pre-sleep arousal and morning tiredness through prior-day daily stress and hassles. In addition, loneliness had indirect effects on daily stress/hassles through prior-night sleep quality and pre-sleep arousal. These findings suggest that interventions aimed at mitigating the effects of loneliness should also incorporate components that target modifiable risk factors such as sleep and stress, as well as approaches that enhance social connectedness.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interests to declare.

DATA AVAILABILITY STATEMENT

Data available upon reasonable request.

ETHICS STATEMENT

The study was approved by the University Department's Research Ethics Committee (PSYC-692).

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