

Combining Short-term Online Mindfulness with Natural Sounds to Reduce Pre-Sleep Problematic Social Media Use: A Cross-over Randomized Control Trial.

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Table of Contents

Original Manuscript..... 5

Supplementary Files..... 38

 Figures 39

 Figure 1..... 40

 Figure 2..... 41

 Multimedia Appendixes 42

 Multimedia Appendix 1..... 43

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Abstract

Background: Pre-sleep problematic social media use (PSMU) among tertiary students has been shown to impair sleep quality, academic performance, and daytime functioning, highlighting the urgent need for effective interventions.

Objective: This study was designed to assess whether short-term online interventions, such as one or two weeks of mindfulness-based intervention (MBI), natural sounds (NS), or their combination, could effectively alleviate pre-sleep PSMU among college students.

Methods: The experiment adopted a randomized 2×2 crossover design. Participants were 154 students enrolled at a university in China, ranging in age from 17 to 24 years (mean 18.78, SD 0.79). The sample consisted of 92 females (59.74%), 54 males (35.06%), and 8 individuals (5.19%) who opted not to disclose their gender. During the first week, participants were randomly allocated to one of two groups: the MBI (N = 78) or the NS intervention (N = 76). In the second week, each group was further randomized: the week-one mindfulness group was divided into Group A (M+M) and Group B (M+N), while the week-one NS group was divided into Group C (N+N) and Group D (N+M).

Results: Both the MBI and NS led to significant short-term reductions in pre-sleep PSMU after one week (mindfulness: $t(50) = -2.59$, $p = .012$, Hedges' $g = -0.32$; natural sounds: $t(46) = -3.74$, $p < .001$, Hedges' $g = -0.50$). Over the two-week period, two weeks of NS produced a marginal effect ($p = .078$). Group A showed no significant change (W0–W2: $t = -0.24$, $p = .81$), whereas Group B produced significant improvement (W0–W2: $t = 2.27$, $p = .025$, 95% CI [0.42, 6.10]). Group C showed a marginal effect (W0–W2: $t = 1.77$, $p = .078$), while Group D yielded the largest gain (W0–W2: $t = 2.72$, $p = .007$, 95% CI [1.09, 6.91]).

Conclusions: One week of online MBI or NS significantly alleviated pre-sleep PSMU among college students. However, two weeks of MBI did not yield significant results. Two weeks of NS produced a marginal effect, warranting further investigation. Importantly, the combined two-week intervention of MBI and NS demonstrated significant improvements, effectively alleviating pre-sleep PSMU among Chinese university students.

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Original Manuscript

Combining Short-term Online Mindfulness with Natural Sounds to Reduce Pre-Sleep Problematic Social Media Use: A Cross-over Randomized Control Trial.

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Abstract

Background Pre-sleep problematic social media use (PSMU) among tertiary students has been shown to impair sleep quality, academic performance, and daytime functioning, highlighting the urgent need for effective interventions.

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Methods The experiment adopted a randomized 2×2 crossover design. Participants were 154 students enrolled at a university in China, ranging in age from 17 to 24 years (mean 18.78, SD 0.79). The sample consisted of 92 females (59.74%), 54 males (35.06%), and 8 individuals (5.19%) who opted not to disclose their gender. During the first week, participants were randomly allocated to one of two groups: the MBI (N = 78) or the NS intervention (N = 76). In the second week, each group was further randomized: the week-one mindfulness group was divided into Group A (M+M) and Group B (M+N), while the week-one NS group was divided into Group C (N+N) and Group D

(N+M).

Results Both the MBI and NS led to significant short-term reductions in pre-sleep PSMU after one week (mindfulness: $t(50) = -2.59, p = .012$, *Hedges' g* = -0.32; natural sounds: $t(46) = -3.74, p < .001$, *Hedges' g* = -0.50). Over the two-week period, two weeks of NS produced a marginal effect ($p = .078$). Group A showed no significant change (W0–W2: $t = -0.24, p = .81$), whereas Group B produced significant improvement (W0–W2: $t = 2.27, p = .025$, 95% CI [0.42, 6.10]). Group C showed a marginal effect (W0–W2: $t = 1.77, p = .078$), while Group D yielded the largest gain (W0–W2: $t = 2.72, p = .007$, 95% CI [1.09, 6.91]).

Conclusion One week of online MBI or NS significantly alleviated pre-sleep PSMU among college students. However, two weeks of MBI did not yield significant results. Two weeks of NS produced a marginal effect, warranting further investigation. Importantly, the combined two-week intervention of MBI and NS demonstrated significant improvements, effectively alleviating pre-sleep PSMU among Chinese university students.

Key words: Short-term online; Mindfulness; Natural sounds; Pre-sleep Problematic social media use; Combination intervention.

Introduction

As of December 2024, Chinese internet users spent an average of 28.7 hours online per week [1]. Notably, individuals aged 10–29 accounted for 26.1% of the total internet user population, representing a key demographic in terms of internet engagement [1]. Recent statistics indicate that social media platforms are used by approximately 253 million individuals in America, representing nearly 73% of the national population [2]. In contemporary society, excessive social media use

among university students represents a growing public health and psychological concern. Research has associated this overuse with several adverse outcomes, including insomnia and sleep deprivation [3], higher likelihood of depression, anxiety, and loneliness [4], reduced academic performance and attentional capacity [5], and, occasionally, addictive behaviors [6].

Excessive engagement with social media prior to bedtime has been found to have particularly detrimental effects on students' sleep patterns. Previous studies have consistently reported that pre-sleep problematic social media use (PSMU) and the pervasive presence of electronic devices are associated with reduced total sleep duration among adolescents [7,8]. Adolescents who frequently rely on laptops—for activities such as gaming, online communication, and general internet use—and mobile phones tend to exhibit poorer sleep habits. Compared with peers who use electronic devices less frequently, these adolescents are also more likely to experience daytime fatigue [9]. Given this context, identifying effective strategies to reduce social media use frequency has become a continuing research priority. Among these strategies, Mindfulness-Based Intervention (MBI) and natural sounds (NS) have emerged as promising and effective approaches.

Mindfulness, which traces its roots to ancient Buddhist traditions [10], refers to the intentional focus of attention on the present moment with openness, curiosity, and non-judgmental awareness [11]. Research has demonstrated that mindfulness can effectively enhance emotional regulation, reducing levels of anxiety, depression, and stress [12,13], alleviate insomnia and improve sleep quality [14,15], and improve attention control, working memory, and concentration [16,17]. Evidence also indicates that mindfulness can mitigate physiological stress responses, improve immune function, and ease chronic pain [18,19]. Beyond these effects, mindfulness practice has also been found to be associated with lower levels of PSMU, diminished fear of missing out, and improve self-control [20]. The accumulated evidence demonstrates the broad psychological, physiological, and behavioral benefits of mindfulness practice.

Natural sounds (NS), defined as sounds originating from the natural environment, have been

shown to exert restorative effects [21,22]. In this context, restoration describes the process through which depleted physical, mental, and social resources are renewed or replenished following sustained adaptive demands [23]. Empirical findings indicate that certain types of natural sounds—such as birdsong, flowing water, or fountain sounds—exert particularly strong restorative effects by attenuating sympathetic nervous system activation after exposure to psychological stress, thereby contributing to stress reduction [24]. Beyond stress recovery, NS interventions have also been associated with improvements in sleep quality [25], enhanced attention and cognitive restoration [26], and reductions in negative emotions alongside increases in positive affective experiences [27].

Intervention for PSMU Through Mindfulness-Based Interventions (MBIs)

The exploration of mindfulness-based interventions (MBIs) for PSMU has developed into a substantial line of inquiry. Mindfulness has been theoretically linked to the cognitive-behavioral mechanisms underpinning social media engagement [28], and accumulating empirical evidence suggests a direct interaction between mindfulness and technology-related behaviors. For example, it has been demonstrated that mindfulness not only reduces problematic smartphone use but also enhances academic self-efficacy, which in turn inhibits the escalation of PSMU [29]. A meta-analysis of 14 studies involving 5,355 participants provides further empirical support for this conclusion, demonstrating a robust inverse relationship between trait mindfulness and social media use ($r = -0.37$, 95% CI $[-0.42, -0.33]$, $k = 14$, $p < .001$) [30]. Because trait mindfulness encompasses dimensions such as acting with awareness, non-judging of experience, describing, non-reactivity to inner experience, and observing, individuals scoring higher on these dimensions tend to be less prone to PSMU. Notably, individuals with higher mindfulness scores demonstrated fewer symptoms of problematic smartphone use, experienced less internet-related fear, and reported slightly shorter daily screen time [31]. The effect was also observed at the daily level, where adolescents with lower mindfulness and reduced positive affect on one day tended to increase their screen use the following day [32].

Given the close relationship between mindfulness and PSMU, researchers have increasingly turned to MBIs as a practical intervention, particularly in college populations. For instance, a repeated-measures web survey conducted with 261 students found that mindfulness functioned as a significant mediator between depression, anxiety sensitivity, and PSMU severity [33]. A similar pattern emerged, with students aged 18–20 who exhibited lower levels of mindfulness engaging in more frequent smartphone use [28]. Experimental evidence further supports the efficacy of MBIs. A randomized controlled trial with 171 female students assigned participants to a 15-minute mindfulness session or to a condition involving unstructured smartphone use. Relative to participants in the smartphone-use condition, those practicing mindfulness exhibited markedly greater elevations in heart rate variability, indicative of improved autonomic regulation and heightened subjective relaxation [34]. A study produced comparable results in a Chinese sample of 44 students: those who received a 30-minute mindfulness session reported lower PSMU, higher state mindfulness, and stronger self-control than those in a neutral audio control condition [35]. In a longer intervention, an eight-week group mindfulness-based cognitive-behavioral program was delivered to students exhibiting smartphone addiction. Compared with a control condition, those in the intervention demonstrated significant reductions in smartphone addiction at multiple follow-up assessments, including weeks 1, 8, 14, and 20 [36]. Previous research on MBI for PSMU has encompassed both brief single-session interventions and extended programs lasting up to eight weeks. Compared with the standard eight-week format, shorter adaptations of mindfulness-based stress reduction may be particularly valuable for individuals whose primary aim is to alleviate psychological distress but whose time constraints may limit their willingness to participate [37]. It argued that abbreviated interventions are more likely to sustain participant engagement and adherence by maintaining novelty and reducing attrition rates. Even short-term interventions appear sufficient to allow participants to acquire essential mindfulness skills [38]. Indeed, brief MBIs have been shown to influence health-related outcomes after a single exposure, with effects observed following

interventions as short as five minutes. Taken together, these findings suggest that both brief and extended mindfulness interventions are effective in alleviating PSMU among college students. A key unresolved question is whether one- or two-week MBIs can achieve comparable outcomes, which necessitates systematic investigation.

Intervention for PSMU Through NS

NS represent a potential approach for alleviating PSMU and warrant further empirical exploration. Although research directly examining NS as an intervention for PSMU is scarce, thereby giving this study pioneering significance, the theoretical and empirical foundations for such an approach are not without precedent.

Regarding PSMU, the Compensatory Internet Use Theory is particularly relevant. It posits that individuals who experience stress, loneliness, social anxiety, low self-esteem, or other negative emotions in everyday life may turn to online activities—such as social media, gaming, or online shopping—as compensatory strategies [39]. Numerous studies have provided support for the explanatory value of this theory [40,41]. For instance, depression has consistently shown a significant and at least medium-sized association with problematic mobile phone use. Anxiety is also reliably associated with problematic use, though with somewhat smaller effect sizes. Stress demonstrates relatively stable associations, with effect sizes varying from small to medium [42].

At the same time, accumulating evidence suggests that NS can effectively reduce stress, depression, and anxiety [43,44]. The Stress Reduction Theory serves as a theoretical framework explaining these phenomena. It posits that human beings have developed adaptive preferences for natural environments over the course of evolution. Exposure to natural environmental cues—whether visual or auditory—can rapidly elicit positive emotional responses and attenuate both physiological and psychological stress [45]. Ulrich's seminal study empirically supported this claim, demonstrating

that patients exposed to natural views recovered more quickly from surgery than those who were not [46].

Taken together, these findings raise a critical question: given that NS are effective in relieving stress, depression, and anxiety—factors strongly implicated in PSMU—can NS indirectly alleviate PSMU by mitigating these underlying conditions, or might NS exert a more direct influence on PSMU itself? Evidence in this regard is beginning to emerge. For instance, college students randomly allocated to either a natural environment recall condition ($n = 80$) or an urban environment recall condition ($n = 79$). Results indicated that participants who recalled a natural environment reported significantly lower desire for smartphone use compared with those recalling an urban environment [47]. Although this study relied on recall rather than direct exposure to NS, the findings nonetheless provide important preliminary evidence suggesting that natural environmental cues may attenuate problematic smartphone-related behaviors.

Addressing this question is not only theoretically significant but also practically urgent, as previous studies have not yet systematically explored the role of NS in the context of PSMU. Consequently, this study holds pioneering significance in advancing our understanding of NS as a potential intervention for PSMU.

Exploring the MBI combined with NS

The integration of MBI with NS has long been recognized for its potential benefits. Listening to NS has been shown to calm the mind and enhance concentration [48]. Studies have demonstrated that combining water soundscapes—such as those of oceans, rivers, or lakes—with guided meditation can effectively promote physical and psychological relaxation [49]. Evidence indicates that mindfulness significantly mediates the relationship between natural contact and PSMU [44].

The present work resonates with the broader concept of Mindfulness Plus (Mindfulness+), defined as the integration of MBI with other evidence-based interventions to augment the effects of

mindfulness [50]. Several Mindfulness+ approaches have already yielded promising outcomes, including combinations of mindfulness with pharmacological treatments, behavioral activation [51] and reflection training [52]. Although the specific integration of MBI with NS has rarely been examined in the context of reducing PSMU, precedents for this approach exist in other domains. In a four-week online meditation course, 97 participants were assigned at random to either a “nature group,” which received guided meditation accompanied by natural sounds, or a “control group,” which listened to soothing water sounds simulating water therapy. Findings indicated that meditation led to improvements in participants’ mindfulness, nature connectedness, and pro-environmental behavior [53].

Taken together, these findings suggest that combining MBI with NS carries both theoretical and practical value and merits further exploration. As far as we are aware, the current study constitutes the first experimental attempt to evaluate whether this combined intervention could also mitigate pre-sleep PSMU among college students.

The Purpose and Research Questions of the Present Paper

As mentioned above, long-term pre-sleep PSMU has been shown to exert detrimental effects on college students’ sleep quality [8,54], academic performance [5], and daytime fatigue [9]. In this context, the present study seeks to evaluate two short term interventions for alleviating pre-sleep PSMU in this population. Specifically, two interventions—MBI and NS—will be delivered through online audio sessions.

The study aims to evaluate whether brief interventions, lasting one to two weeks, can reduce pre-sleep PSMU in college students. Furthermore, it introduces a novel Mindfulness Plus approach by alternating the two interventions across consecutive weeks, thereby examining whether the combined application produces additional or distinct benefits relative to each intervention alone.

Accordingly, the present research is guided by the following questions and hypotheses:

Questions 1: Will one or two weeks of MBI significantly alleviate pre-sleep PSMU in college students?

H1a: One week of MBI will significantly alleviate pre-sleep PSMU in college students.

H1b: Two weeks of MBI will significantly alleviate pre-sleep PSMU in college students.

Questions 2: Will one or two weeks of NS significantly alleviate pre-sleep PSMU in college students?

H2a: One week of NS will significantly alleviate pre-sleep PSMU in college students.

H2b: Two weeks of NS will significantly alleviate pre-sleep PSMU in college students.

Question3: Will an intervention combining MBI and NS in the first week and NS in the second week, or vice versa) significantly alleviate pre-sleep PSMU in college students?

H3: The combined MBI and NS intervention in week one followed by NS in week two, or vice versa) significantly alleviates pre-sleep PSMU among college students.

Methods

Participants

In total, 154 university students from northern China participated in the study. Ethical approval was granted by the university's institutional review board, confirming that all procedures complied with established ethical standards. Written informed consent was obtained from all participants before data collection.

Among the 154 participants (age range: 17–24 years; mean 18.78, SD 0.79), 92 (59.74%) identified as female, 54 (35.06%) as male, and 8 (5.19%) chose not to disclose their gender. All participants were Chinese college students, the majority of whom ($n = 153$) were undergraduates, with only one graduate student included in the sample. In addition, 149 participants (96.75%) indicated that they had not engaged in any formal mindfulness practice during the month preceding the study.

Design and Procedure

This study adopted a randomized 2×2 crossover design with two intervention conditions: mindfulness-based intervention (MBI) and natural sounds (NS). In the first week, participants were randomly allocated to one of two conditions: the MBI condition or the NS condition. In the second week, both groups underwent a further randomization into two subgroups. A comprehensive schematic of the experimental procedure appears in Figure 1.

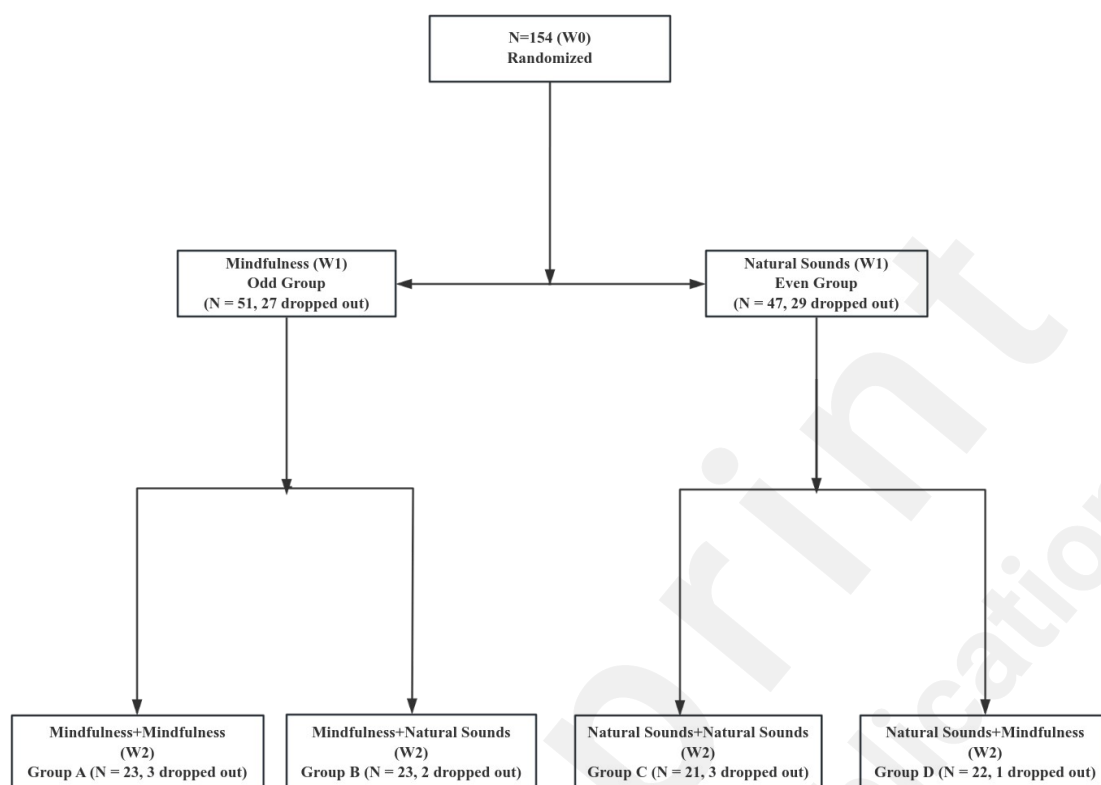
Prior to the commencement of the experiment, all participants were required to sign the informed consent and complete pre-test questionnaires. The first stage of the experiment lasted for 9 days. On Day 0 and Day 9, participants completed the pre-test and post-test questionnaires, respectively, while Days 1 to 8 were designated for the administration of the experimental audio materials.

During this stage, participants were assigned random identification codes and subsequently allocated into two groups according to odd and even numbering. Those in the odd-numbered group were instructed to listen to the MBI audio for ten minutes each night before bedtime, while participants in the even-numbered group listened to NS audio during the same period. Upon completing the first stage, each participant received 80 RMB in compensation on Day 9.

The second stage of the experiment followed a similar 9 days structure. Only participants who had completed the first stage were eligible to continue. Days 10 to 16 were designated as the intervention period, and all participants were required to complete the post-test questionnaire before Day 17. On Day 18, the participation fees were finalized and distributed.

In this stage, randomization was conducted again within the odd- and even-numbered groups. The odd-numbered group was further divided into Group A and Group B, while the even-numbered group was divided into Group C and Group D. Groups A and C continued with the same intervention as in the first week, whereas Groups B and D crossed over to the alternative condition (i.e., Group B switched from MBI to NS, and Group D switched from NS to MBI). Participants who completed the second stage received an additional compensation of 50 RMB.

Figure 1. Flow chart of the study. W0: the baseline measurement; W1: the first-week post-test measurement; W2: the second-week post-test measurement.



Measures

Questionnaires

The experimental questionnaire was administered via the online platform Questionnaire Star [55]. The study assessed social media use using a ten-item adapted version of the original instrument, which was initially developed to evaluate its effects on sleep [56]. Items 1–4 were retained from the original instrument, while items 5–10 were newly developed to align with the research objectives. The Pre-Sleep Social Media Use Scale (PSMUS) was designed to evaluate the patterns of social media engagement before sleep and their subjective effects on sleep quality and next-day performance. Specifically, items 5 and 6 evaluated the duration of social media use on weekdays (Monday to Friday), both prior to going to bed and while in bed, whereas items 7 and 8 assessed the same behaviors during weekends. Responses were recorded on a 5-point scale (less than 30 minutes, 30–60 minutes, 1–2 hours, 2–3 hours, and more than 3 hours). Items 9 and 10 assessed participants'

perceptions of how pre-sleep social media use influenced sleep quality and next-day functioning (e.g., oversleeping, difficulty concentrating) using a 0–4 scale. A total score was calculated on a 0–4 scale, with larger values indicating a greater severity of pre-sleep problematic social media use (PSMU)

Audios

Two types of audio stimuli—mindfulness and natural sounds—were administered through the meditation application NOW [57]. The mindfulness audio, titled *Meditation for Easy Sleep* [58], lasted 9 minutes and 21 seconds and featured only spoken guidance without background music, making it suitable for beginners. The natural sounds audio consisted of recordings of flowing water and bird songs, with a duration of 10 minutes [59].

Method of Analysis

Data analyses were conducted using SPSS [60] and R [61]. T-tests were conducted with SPSS, and linear mixed-effects models were performed using R. All variables met the assumption of normality, and outliers were identified and removed based on the standard deviation method. During the first week, t-tests were used to examine within-group and between-group differences, with effect sizes estimated using *Hedges' g* to provide a more accurate measure of standardized mean differences, particularly in studies with relatively small sample sizes. For the second week, linear mixed-effects modeling was employed to accommodate the repeated-measures design, as this approach can appropriately handle correlated observations within individuals and accommodate both fixed and random effects.

Results

Baseline descriptive statistics for the Pre-Sleep Social Media Use Scale (PSMUS) items are summarized in Table 1. Rated on a 0–4 Likert scale, results indicate that participants engaged in social media use roughly 5–6 days per week before bedtime, both during the hour before sleep (mean 3.58, SD 0.94) and while in bed (mean 3.55, SD 0.92). The time spent on social media each night

before going to bed (mean 1.68, SD 1.09) and while lying in bed before sleep (mean 1.84, SD 1.13) generally ranged from 0.5 to 1 hour. These durations were consistent with participants' weekly patterns, including the time spent before bed (mean 1.81, SD 1.17) and while lying in bed (mean 1.84, SD 1.05). However, during weekends, the time spent on social media increased, averaging 2.25 hours (mean 2.25, SD 1.10) before going to bed and 2.22 hours (mean 2.22, SD 1.09) while lying in bed, typically ranging from 1 to 2 hours. When participants rated the subjective impact of pre-sleep social media use, they reported effects on both sleep quality (mean 1.77, SD 1.16) and next-day performance (mean 1.68, SD 1.19), although the perceived impact was relatively small.

Table 1. Descriptive Statistics for the Pre-Sleep Social Media Use Scale (PSMUS) Items at Baseline (N = 154).

Item	M(SD)
1	3.58(0.94)
2	3.55(0.92)
3	1.68(1.09)
4	1.84(1.13)
5	1.81(1.17)
6	1.84(1.05)
7	2.25(1.10)
8	2.22(1.09)
9	1.77(1.16)
10	1.68(1.19)
Overall Scale	22.20(10.85)

Analysis of PSMUS Data for Week 1

To preliminarily examine the immediate effects of the interventions, paired-sample t tests were performed within each group, comparing baseline (W0) and first-week posttest (W1) scores. As shown in Table 2, participants in the odd-numbered mindfulness group (OM) demonstrated a significant reduction in PSMUS scores from W0 (mean 21.84, SD 7.48) to W1 (mean 19.37, SD 7.66; $t(50) = -2.59$; $p = .012$), corresponding to a small-to-moderate effect size (*Hedges' g* = -0.32). Similarly, the even-numbered natural sounds group (EN) showed a significant decrease from W0 (mean 22.13, SD 6.92) to W1 (mean 18.17, SD 8.77; $t(46) = -3.74$; $p < .001$), with a moderate effect size (*Hedges' g* = -0.50).

Between-group comparisons revealed no significant differences at either baseline or week 1 (both $p > .700$), indicating that both groups started from comparable levels and that each intervention was similarly effective during the first week. Collectively, these preliminary findings provide initial evidence that both mindfulness audio and natural sounds effectively reduce pre-sleep problematic social media use (PSMU), supporting further exploration of longer-term and sequential intervention effects using mixed-effects modeling.

Table 2. Comparison of data for Pre-Sleep Social Media Use Scale (PSMUS) at Week 1.

^a OM: Odd	Group	N	W0 ^c	W1 ^d	W1-W0		
			<i>M(SD)</i>	<i>M(SD)</i>	<i>t</i>	<i>g</i>	<i>p</i>
	OM ^a	51	21.84(7.48)	19.37(7.66)	-2.59 ^f	-0.32	.012
	EN ^b	47	22.13(6.92)	18.17(8.77)	-3.74 ^g	-0.50	< .001
	<i>t</i>	N/A ^e	-0.195	0.724	N/A ^e	N/A ^e	N/A ^e

number group of mindfulness.

^bEN: Even number group of natural sounds.

^cW0: the baseline measurement.

^dW1: the first-week post-test measurement.

^eN/A: not applicable.

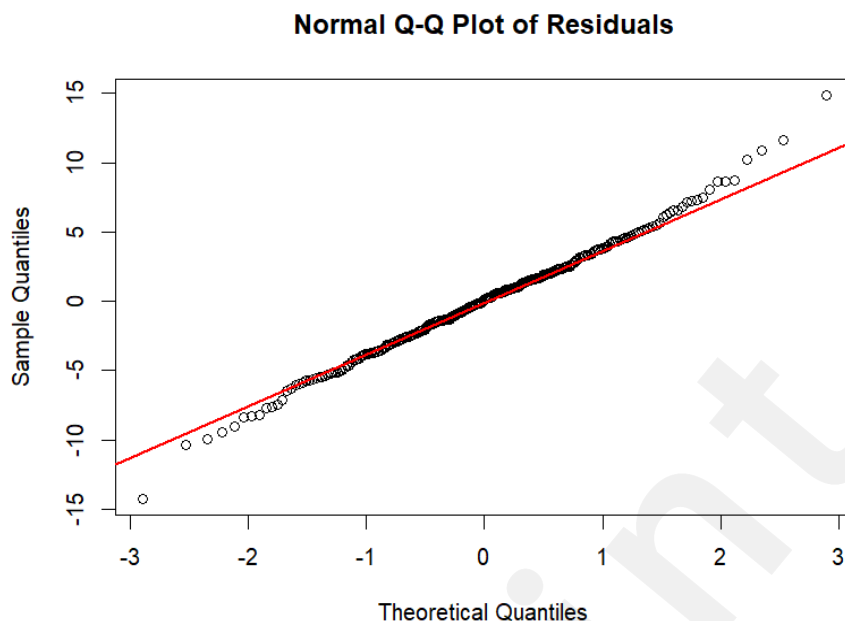
^f $p < .05$

^g $p < .001$

Analysis of PSMUS Data for Week 2 and 2 Weeks

To assess the differential effects of intervention sequences over two weeks, a linear mixed-effects model was fitted, with post-intervention scores predicted by time (week), sequence group (seq), and their interaction, and a random intercept included for participants. The model demonstrated satisfactory overall fit, with a marginal R^2 of 0.052, indicating that the fixed effects accounted for 5.2% of the variance, and a conditional R^2 of 0.589, indicating that the full model, including random effects, explained 58.9% of the variance. The Q-Q plot of residuals (Figure 2) demonstrated approximate normality, with points largely following the reference line and only minor tail deviations, confirming adherence to the normality assumption and supporting model validity.

Figure 2. Normal Q-Q plot of residuals from the linear mixed-effects model.



A significant Week $\times$ Sequence interaction ($p < .05$) suggested that the effects of the interventions varied over time depending on sequence. Follow-up pairwise comparisons were conducted to assess changes within each sequence group across timepoints. Table 3 summarizes contrasts from baseline (W0) to the second-week post-test (W2), and from the first-week post-test (W1) to W2.

Group A (mindfulness + mindfulness) showed no significant change from W0 to W2 (estimate = -0.35 , $t = -0.24$, $p = .809$, 95% CI [-3.19 , 2.49]) or from W1 to W2 (estimate = -2.30 , $t = -1.60$, $p = .111$), suggesting that extending mindfulness across both weeks did not produce additional benefits.

Group B (mindfulness + natural sounds) exhibited a significant improvement from W0 to W2 (estimate = 3.26 , $t = 2.27$, $p = .025$, 95% CI [0.42 , 6.10]). The W1 to W2 contrast was non-significant (estimate = -1.65 , $t = -1.15$, $p = .253$), implying that most of the benefit occurred during the initial mindfulness week, with natural sounds helping to maintain but not enhance the effect.

Group C (natural sounds + natural sounds) showed a marginal trend toward improvement from W0 to W2 (estimate = 2.67 , $t = 1.77$, $p = .078$, 95% CI [-0.31 , 5.64]), with no significant change from W1 to W2 (estimate = -1.24 , $t = -0.82$, $p = .412$). This pattern suggests a modest benefit that

did not reach conventional significance thresholds.

Group D (natural sounds + mindfulness) displayed a significant reduction from W0 to W2 (estimate = 4.00, $t = 2.72$, $p = .007$, 95% CI [1.09, 6.91]), while the W1–W2 contrast was non-significant (estimate = 0.86, $t = 0.59$, $p = .558$), indicating that the addition of mindfulness in the second week consolidated and maintained the gains achieved during the first week of natural sounds.

Together, these findings suggest that the sequence and timing of interventions matter, with mixed or alternating modalities (e.g., Groups B and D) yielding stronger and earlier reductions in PSMUS than continuous exposure to a single intervention type.

Table 3. Within-sequence pairwise contrasts (W2 and 2 weeks).

Sequence	Contrast	Estimate	N	SE	Df^a	t	p^b	95% CI
Group A^c (M+M)	W0 ^g - W2 ⁱ	-0.35	23	1.44	170	-0.24	0.809	[-3.19, 2.49]
Group A^c (M+M)	W1 ^h - W2 ⁱ	-2.30	23	1.44	170	-1.60	0.111	[-5.15, 0.54]
Group B^d (M+N)	W0 ^g - W2 ⁱ	3.26	23	1.44	170	2.27 ^j	0.025	[0.42, 6.10]
Group B^d (M+N)	W1 ^h - W2 ⁱ	-1.65	23	1.44	170	-1.15	0.253	[-4.49, 1.19]
Group C^e (N+N)	W0 ^g - W2 ⁱ	2.67	21	1.51	170	1.77	0.078	[-0.31, 5.64]
Group C^e (N+N)	W1 ^h - W2 ⁱ	-1.24	21	1.51	170	-0.82	0.412	[-4.21, 1.74]
Group D^f (N+M)	W0 ^g - W2 ⁱ	4.00	22	1.47	170	2.72 ^k	0.007	[1.09, 6.91]
Group D^f (N+M)	W1 ^h - W2 ⁱ	0.86	22	1.47	170	0.59	0.558	[-2.04, 3.77]

^adf: Kenward–Roger.

^b p -values: Holm-adjusted within each sequence.

^cGroup A, a two-week mindfulness intervention.

^dGroup B: a mindfulness intervention in the first week and natural sounds in the second week.

^eGroup C: a two-week natural sounds intervention.

^fGroup D: a natural sounds intervention in the first week and mindfulness in the second week.

^gW0: the baseline measurement.

^hW1: the first-week post-test measurement.

ⁱW2: the second-week post-test measurement.

^j $p < .05$

^k $p < .01$

To complement the inferential statistics, estimated marginal means were examined across the three time points for each sequence group (Table 4). These descriptive trends provide a clearer depiction of temporal trajectories and help interpret the significant Week $\times$ Sequence interaction.

Group A (M+M) exhibited minimal change, with means shifting from 20.22 at W0 to 20.57 at W2, consistent with the non-significant contrasts. Group B (M+N) showed the steepest drop from 22.26 (W0) to 19.00 (W2), with the largest change occurring between W0 and W1 (17.35), suggesting the mindfulness component was the primary driver of improvement. Group C (N+N) declined from 23.14 at baseline to 20.48 at W2, reflecting initial improvement followed by a slight rebound. Group D (N+M) demonstrated a progressive decline across time points: 22.64 (W0), 19.50 (W1), and 18.64 (W2), reflecting sustained improvement throughout the two-week period.

In summary, the estimated means highlight that alternating interventions (particularly mindfulness followed by natural sounds, or vice versa) were more effective in reducing pre-sleep social media use than repeating a single modality across both weeks.

Table 4. Estimated marginal means (with 95% CIs).

Sequence	Week (W)	Mean (95% CI)
Group A ^a (M+M)	W0	20.22 [17.17, 23.27]
Group A ^a (M+M)	W1	18.26 [15.21, 21.31]
Group A ^a (M+M)	W2	20.57 [17.51, 23.62]
Group B ^b (M+N)	W0	22.26 [19.21, 25.31]
Group B ^b (M+N)	W1	17.35 [14.30, 20.40]
Group B ^b (M+N)	W2	19.00 [15.95, 22.05]
Group C ^c (N+N)	W0	23.14 [19.95, 26.34]
Group C ^c (N+N)	W1	19.24 [16.04, 22.43]
Group C ^c (N+N)	W2	20.48 [17.28, 23.67]

Group D^d (N+M)	W0	22.64 [19.52, 25.76]
Group D^d (N+M)	W1	19.50 [16.38, 22.62]
Group D^d (N+M)	W2	18.64 [15.52, 21.76]

^aGroup A, a two-week mindfulness intervention.

^bGroup B: a mindfulness intervention in the first week and natural sounds in the second week.

^cGroup C: a two-week natural sounds intervention.

^dGroup D: a natural sounds intervention in the first week and mindfulness in the second week.

Discussion

The present study employed a randomized 2×2 crossover design to investigate the short-term effects of mindfulness-based intervention (MBI), natural sounds (NS), and their combinations (MBI + NS or NS + MBI) on problematic social media use (PSMU) among Chinese college students. The findings provide several important insights. First, both one-week interventions of MBI ($t(50) = -2.59$, $p = .012$) and NS ($t(46) = -3.74$, $p < .001$) significantly reduced PSMU, suggesting that even a brief, single-week exposure to either approach can yield measurable benefits. Second, analysis of the two-week sequences revealed differentiated patterns. Specifically, the combined interventions—Group B (M+N, $t = 2.27$, $p = .025$, 95% CI [0.42, 6.10]) and Group D (N+M, $t = 2.72$, $p = .007$, 95% CI [1.09, 6.91])—produced significant reductions in PSMU, highlighting the potential synergistic effect of integrating MBI and NS. Whereas Group C (N+N) demonstrated only a marginal trend ($p = .078$) and Group A (M+M) showed no significant improvement—pointing to limited efficacy of two-week repeated single interventions—the results emphasize the advantage of short-term, diversified interventions and the greater benefits of combined modalities.

Effectiveness of Short-term Online NS on Pre-sleep PSMU.

Although research on NS interventions has expanded, most studies have concentrated on alleviating stress, depression, and anxiety [43,47], with relatively limited attention given to their role in mitigating pre-sleep PSMU among college students. A one-week NS intervention significantly

alleviated pre-sleep PSMU, consistent with findings that recalling natural environments can diminish the urge to use smartphones [47]. Conversely, the two-week NS intervention showed only a marginal trend, falling short of statistical significance. This limited significance may stem from methodological constraints, such as the relatively small sample size, which could have lowered statistical power and increased the probability of nonsignificant findings despite observed improvements.

Short-term exposure to NS may be particularly effective in alleviating pre-sleep PSMU among college students for several reasons. From the perspective of Stress Recovery Theory (SRT), NS rapidly elicit positive emotional responses, lower physiological arousal, and promote relaxation [45], which can counteract the heightened stress or restlessness that frequently precipitates excessive smartphone use before sleep. According to the Cognitive-Incidental-Use Theory (CIUT), social media use can function as a compensatory strategy for coping with daily stress, loneliness, and social anxiety [39]. NS offers a form of low-demand cognitive engagement that gently captures attentional resources, thereby diverting focus from habitual smartphone use and fostering self-regulation. The brevity of the intervention also helps maintain participant engagement and novelty, reducing the risk of habituation or fatigue associated with prolonged exposure. Additionally, incorporating NS listening before bedtime establishes a structured alternative behavior [62], providing students with an accessible and healthier coping mechanism to displace maladaptive social media reliance. Collectively, these mechanisms explain why a brief natural music intervention can effectively reduce pre-sleep social media use in this population.

Overall, this study provides a meaningful contribution by extending the application of NS interventions to the context of pre-sleep PSMU. Future research should consider recruiting larger and more diverse samples to enhance statistical power and improve the generalizability of findings. Additionally, it will be important to examine whether longer-term NS interventions produce more

sustained benefits and to further clarify the persistence of post-intervention effects—questions that remain to be systematically addressed.

Effectiveness of Short-term Online MBI on Pre-sleep PSMU

Mindfulness is theoretically linked to the cognitive-behavioral mechanisms underlying social media use [28]. PSMU has been shown to be reduced through mindfulness practice [29], and adolescents with lower mindfulness levels demonstrate a greater tendency to increase smartphone usage the following day [32](Nesi et al., 2025). Individuals with higher mindfulness scores, on the other hand, generally exhibit slightly shorter daily screen time [31](Fendel et al., 2025). A trait mindfulness has been found to be inversely associated with social media use intensity [30] and appears to play a mediating role in the severity of pre-sleep PSMU [40]. Controlled experiments further confirm that both single-session mindfulness interventions [34,35] and 8-week mindfulness-based programs [36] effectively alleviate PSMU. Nevertheless, the efficacy of mindfulness interventions appears to vary by duration. In the present study, a one-week MBI significantly alleviated pre-sleep PSMU among college students, while a two-week intervention failed to reach statistical significance. These duration-dependent inconsistencies may be explained by several factors.

Empirical evidence indicates that a one-week MBI can effectively reduce pre-sleep PSMU, highlighting the consistent efficacy of brief mindfulness interventions across studies. In one investigation, a single 15-minute mindfulness session was administered to 171 female undergraduates, with participants in the intervention group showing significantly greater increases in heart rate variability from baseline compared with a control group engaged in unstructured smartphone use, suggesting improvements in both physiological regulation and psychological well-being [34]. Similarly, another study delivered a single 30-minute mindfulness intervention to 40 Chinese undergraduates, observing a significant reduction in problematic smartphone use [35]. Together, these results highlight the promise of short-term, online mindfulness interventions in

reducing pre-sleep PSMU.

The potential of mindfulness to mitigate pre-sleep PSMU is further supported by evidence of a conceptual link between the two. A meta-analysis of 14 studies found a robust inverse association between trait mindfulness and social media use [30]. In line with this, students who engage less in smartphone use tend to exhibit higher levels of state mindfulness and self-control [35], whereas lower mindfulness is associated with more frequent smartphone use [28]. The present study builds on this literature by demonstrating that even a brief, one-week MBI can lead to significant reductions in pre-sleep PSMU. These findings not only expand the empirical evidence base but also offer valuable insights for future research examining the comparative efficacy of MBIs of varying durations in addressing PSMU among college students.

However, findings from the meta-analysis suggest that the impact of mindfulness should not be presumed to extend across all contexts given the methodological differences among studies [63]. The findings also revealed that the two-week MBI intervention did not significantly reduce pre-sleep PSMU, a result that contradicted the initial hypothesis. This outcome stands in contrast to prior studies demonstrating the effectiveness of mindfulness in reducing problematic smartphone use [29,31], as well as with studies reporting that an eight-week mindfulness program significantly improved outcomes related to smartphone addiction. Several factors may help explain this discrepancy [36].

First, a potential ceiling effect may be present, wherein pretest scores reach a level beyond which further improvements cannot be detected due to the measurement instrument's range limitations, thereby threatening the internal validity of the results [64]. Participants may have experienced substantial benefits during the initial week, leaving limited room for additional measurable gains. Second, habituation may play a role, as repeated exposure to an identical stimulus tends to attenuate the organism's response [65]. Brief interventions may be more effective in the early stages when engagement and curiosity are high, whereas extended exposure could diminish the

perceived impact.

Another possible explanation for the nonsignificant findings concerns the repetitiveness of the intervention materials, which may have attenuated participant engagement over time. Specifically, participants were instructed to listen to the same mindfulness audio repeatedly over the two-week period. Such repetition may have induced a fatigue effect, defined as the decline in performance—including attentional focus, reaction speed, response quality, or physiological functioning—resulting from task repetition, prolonged engagement, or resource depletion [66]. This interpretation is corroborated by the distinct outcomes between the first and second intervention weeks. Subsequent research might explore a staggered curriculum design in MBI delivery, introducing techniques in ascending order of complexity to counteract habituation and promote sustained engagement.

A further factor relates to the overall duration of the intervention itself. Some evidence indicates that longer mindfulness practice programs may unexpectedly yield weaker outcomes [63], a surprising limitation also noted in earlier work [67]. One possible explanation is that shorter interventions better maintain participation and compliance, while extended protocols risk reducing novelty, increasing burden, and causing attrition—all factors that can diminish overall effectiveness [68]. At the same time, brief interventions often provide adequate exposure for acquiring core mindfulness skills, whereas longer programs may not produce proportionally greater benefits [38]. These considerations highlight the need for future MBI studies to carefully calibrate intervention length and systematically assess its impact on both mindfulness acquisition and pre-sleep PSMU.

These findings collectively emphasize the interplay between intervention design and duration in MBI implementation. This calls for developing more diversified and sequentially structured content, alongside identifying the precise dosage required to effectively address pre-sleep PSMU in college populations.

The Combined Interventions of NS and MBI on Pre-sleep PSMU

Developing Mindfulness+, or personalized mindfulness programs tailored for specific purposes,

has emerged as a key research focus in the field of MBI [50]. The combined intervention of MBI and NS produced a significant reduction in pre-sleep PSMU among college students. This integration included two forms: Group B, in which participants received MBI during the first week followed by NS in the second week, and Group D, in which NS was delivered first and MBI in the subsequent week. Both combinations proved effective in alleviating pre-sleep PSMU. These results support previous research indicating that mindfulness mediates the link between natural contact and PSMU, while also demonstrating the added efficacy of combining NS with MBIs [44]. A plausible underlying mechanism involves their joint enhancement of relaxation at both physical and psychological levels [49].

This integrated approach functions through dual mechanisms to reduce pre-sleep social media interference. Externally, NS (e.g., birdsong, flowing water) operate by lowering sympathetic arousal and inducing parasympathetic activation, thereby creating a soothing environment that supports attentional focus [69]. Internally, mindfulness functions by strengthening cognitive-emotional regulation through non-judgmental present-moment awareness, diminishing emotional reactivity to online stimuli [70]. This synergistic effect helps mitigate cognitive and emotional hyperarousal induced by social media use, promotes attentional disengagement from digital stimuli, and enhances a sense of relaxation and safety, ultimately supporting smoother sleep onset.

The present findings extend the scope of research on Mindfulness+, providing empirical evidence for the effectiveness of combining different interventions. In doing so, this study contributes new insights and directions for future investigations into Mindfulness+. Furthermore, given the scarcity of research specifically targeting pre-sleep PSMU through combined interventions, the present findings also enrich the empirical basis for exploring strategies to address pre-sleep PSMU in college populations.

Research Limitations and Future Perspectives

While this research offers novel empirical evidence on the short-term effects of the MBI, NS, and their combined application on pre-sleep PSMU among college students, several limitations should be noted. Because the sample comprised only Chinese college students, the applicability of the findings to other cultures or non-student groups may be limited. Previous research consistently demonstrates that cultural background shapes cognitive processes and moderates intervention efficacy. For instance, research has revealed cross-cultural variations in attention, with Japanese individuals paying greater attention to contextual backgrounds compared to Americans, who concentrate more on central objects [71]. Similarly, it has been noted that mindfulness-based programs are influenced by cultural and social factors [72], and sound interventions are likewise affected by environmental variables, including individual preferences, delivery formats, and cultural context [73]. These findings underscore the importance of designing interventions that are sensitive to both personal and contextual factors. Collectively, these considerations indicate the necessity of cross-cultural validation to determine whether the present findings extend to diverse populations.

The temporal dimension of interventions presents another area for further investigation. While this study assessed one- and two-week protocols, the potential for longer durations to yield sustained benefits or, conversely, diminishing returns remains unexplored. Previous work has suggested that the standard 8-week mindfulness-based stress reduction program is optimal for achieving durable effects, whereas shorter interventions may provide only temporary improvements [68]. Meta-analytic evidence further indicates that intervention duration significantly moderates the efficacy of mindfulness programs, although longer protocols may increase the risk of participant fatigue and decreased engagement [74]. Systematic investigation into the dose-response relationship for MBI and NS interventions targeting pre-sleep PSMU thus represents a critical direction for future research.

From a methodological perspective, relying on self-reported assessments of pre-sleep PSMU may introduce potential biases, including recall errors and social desirability influences. Self-report data are especially susceptible to these distortions [75], and social desirability bias can further threaten the validity of subjective measures [76]. To strengthen methodological rigor, subsequent studies would benefit from incorporating objective metrics—such as smartphone usage analytics or polysomnographic sleep indicators—to complement self-report data, thereby improving both the reliability and ecological validity of the findings.

Future studies should address these limitations by recruiting participants from more diverse cultural, socioeconomic, and age backgrounds to improve the external validity of the findings [71]. Cross-cultural comparisons are particularly needed to evaluate whether the effects of MBI, NS, and their combined use remain consistent across different settings or necessitate culturally specific adaptations. Furthermore, longitudinal research with extended follow-up periods would help clarify the durability of intervention benefits, the possibility of cumulative gains or diminishing returns over time, and the role of participant fatigue in long-term adherence. Prior work has highlighted the significance of intervention duration as a determinant of outcomes, noting that while longer programs may produce more sustained effects, they also carry higher risks of participant dropout [37,67]. In this context, adaptive intervention models—which tailor duration or intensity according to individual progress—could offer valuable insights for optimizing implementation protocols.

In addition, incorporating multimodal assessment methods—such as ecological momentary assessment, digital trace measures of smartphone use, and physiological indicators of sleep quality—would strengthen the reliability of outcomes and reduce the limitations of self-reported data [75,76]. These approaches could also capture real-time fluctuations in pre-sleep behaviors and contextual influences. Future research should further examine potential mediators and moderators, including baseline mindfulness, personality traits, and sleep habits, to identify subgroups most likely to benefit

from specific interventions. Such insights would support the development of more personalized and scalable approaches. Finally, the growing availability of digital platforms offers opportunities to deliver MBI and NS through mobile applications or wearable devices, thereby improving accessibility, reducing costs, and enabling adaptive, real-time intervention delivery [67].

Conclusions

This study examined the efficacy of short-term, online mindfulness-based interventions (MBI) and natural sound (NS) interventions, as well as their combined application, in alleviating pre-sleep problematic social media use (PSMU) among college students. The results demonstrated that a one-week MBI and a one-week NS intervention significantly reduced pre-sleep PSMU. Although the effect of a two-week NS intervention was not statistically significant, it produced a marginal effect ($p = .078$), which warrants further investigation. In contrast, extending MBI to two weeks did not yield additional benefits, potentially due to a fatigue effect. Furthermore, the combined interventions of MBI and NS also significantly alleviated pre-sleep PSMU among college students, providing new empirical evidence for research on Mindfulness+. This study contributes to the literature by highlighting the role of NS interventions and their synergistic application with MBI in mitigating pre-sleep PSMU. It offers empirical support for the theoretical mechanisms underlying both MBI and NS interventions. From a practical standpoint, the findings suggest that short-term, well-structured interventions are both effective and feasible for reducing pre-sleep PSMU among college students. Future research should build upon these findings by examining diverse populations, exploring longer intervention durations, incorporating objective behavioral measures, and systematically investigating different Mindfulness+ configurations. In conclusion, this work underscores the potential of targeted, theory-driven interventions to reduce problematic pre-sleep behaviors and promote healthier sleep habits among young adults.

Data Availability

The datasets generated and analyzed during the current study can be obtained from the corresponding author upon reasonable request.

Conflicts of Interest

None declared.

Multimedia Appendix 1

The full version of the Pre-Sleep Social Media Use Scale (PSMUS).

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Abbreviations

EN: Even number group of natural sounds

MBI: mindfulness-based intervention

MBIs: mindfulness-based interventions

NS: natural sounds

OM: Odd number group of mindfulness

PSMU:Pre-sleep problematic social media use

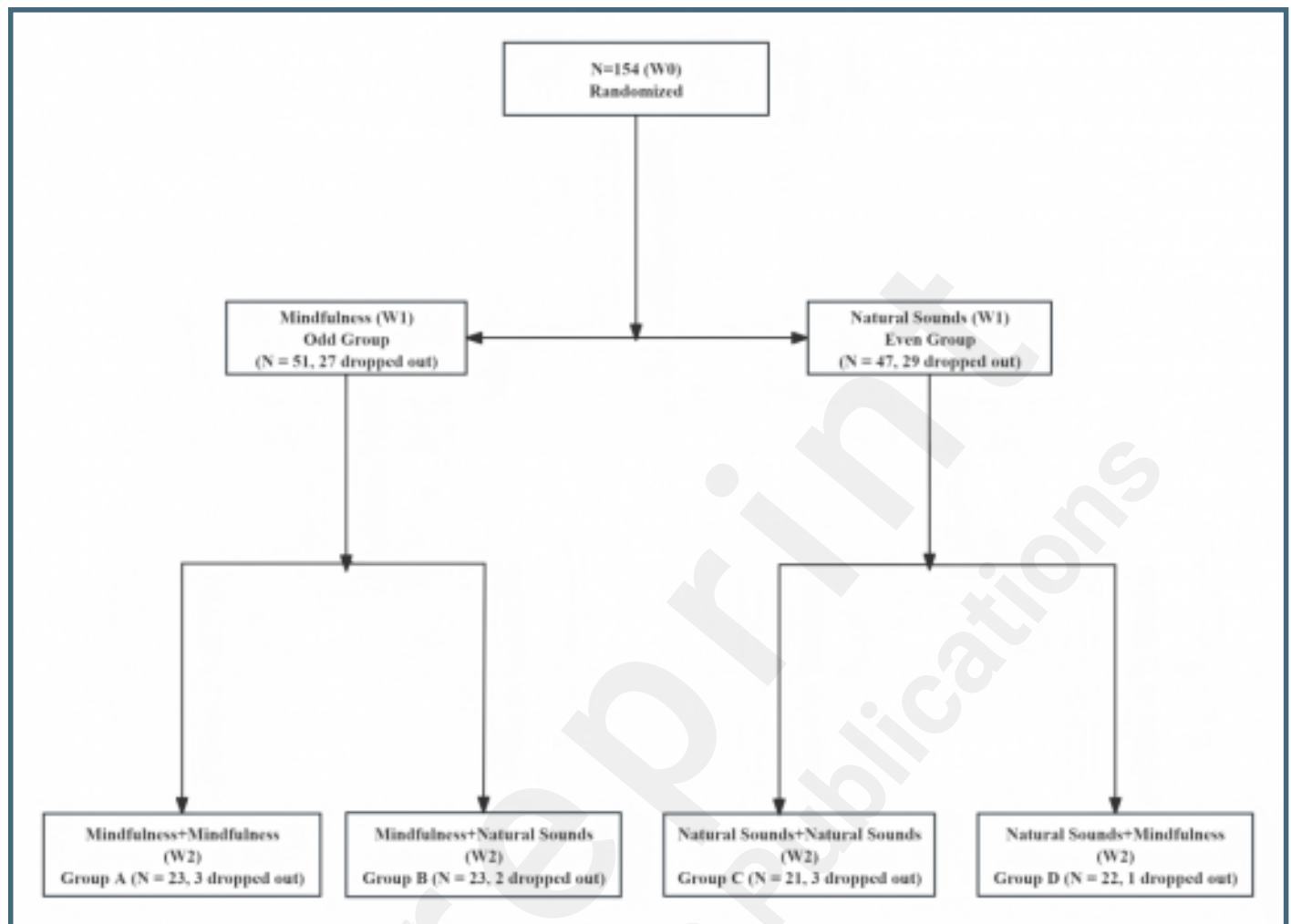
PSMUS: Pre-sleep social media use scale



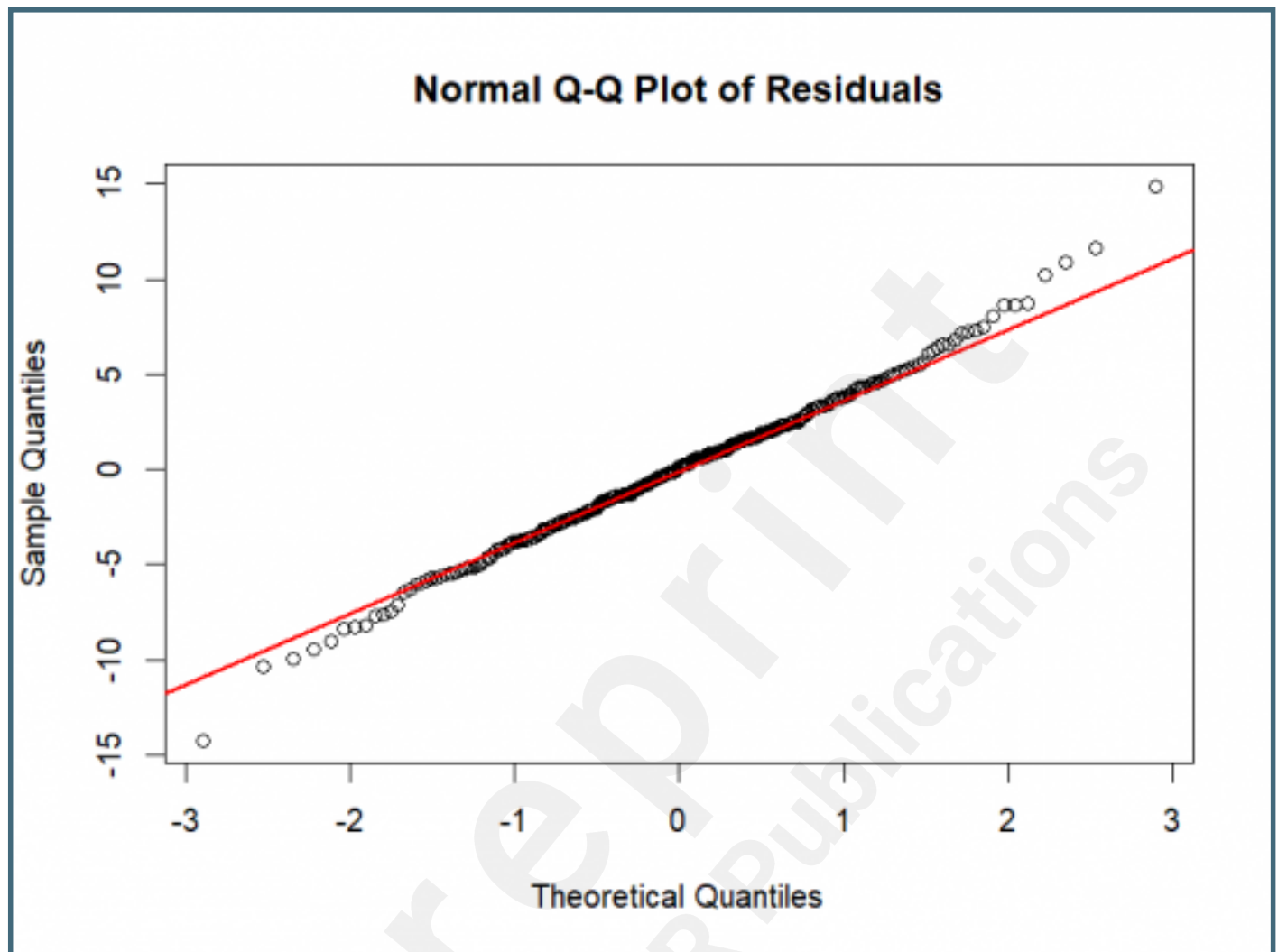
Supplementary Files

Figures

Flow chart of the study.



Normal Q-Q Plot of Residuals.



Multimedia Appendixes

The full version of the Pre-Sleep Social Media Use Scale (PSMUS).

URL: <http://asset.jmir.pub/assets/696dbbb3fd3b54ec920393353df5febe.pdf>

