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Treating subclinical and clinical symptoms of insomnia with a mindfulness-based smartphone application: A pilot study

Tiffany Low[a], Russell Conduit[a], Prerna Varma[a,b], Hailey Meaklim[a,b], Melinda L. Jackson[a,b,*]

[a] School of Health and Biomedical Sciences, RMIT University, Melbourne, Australia
[b] Turner Institute for Brain and Mental Health, School of Psychological Sciences, Monash University, Melbourne, Australia

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ABSTRACT

Background/objectives: Emerging research suggests that face-to-face group mindfulness-based therapies are an effective intervention for insomnia. This pilot study examined the effectiveness of a mindfulness-based smartphone application for improving objectively-measured sleep, self-reported sleep, insomnia severity, pre-sleep arousal and daytime mood.

Method: A community sample of 23 adults with subclinical to moderately severe symptoms of insomnia were randomized to either a mindfulness or progressive muscle relaxation (PMR) smartphone application for 40 or 60 days. Objective sleep outcomes assessed using actigraphy, and self-report measures of total wake time, cognitive and somatic pre-sleep arousal, and daytime positive and negative affect were assessed for 14 nights at baseline and post-intervention. Insomnia severity was recorded at baseline and post-intervention.

Results: A greater reduction in sleep onset latency was observed in the mindfulness group over time, relative to the PMR group. The mindfulness group also reported medium effect size improvements for sleep efficiency. No significant interaction effects were found for self-reported sleep measures, however, main effects of time were found for both groups for total wake time, insomnia severity, cognitive pre-sleep arousal, and daytime positive and negative affect.

Conclusions: These preliminary findings suggest that both mindfulness and PMR smartphone applications have the potential to improve symptoms of insomnia. In particular, this mindfulness-based smartphone application may improve sleep onset latency and reduce the duration of night-awakenings. Further research exploring digital therapeutics as a self-help option for those with insomnia is needed.

1. Introduction

Insomnia is considered a significant public health concern, which causes signficiant daytime impairment and distress. An estimated 6–10% of individuals meet criteria for an insomnia disorder (Morin and Jarrin, 2013) and approximately 20–35% of Australians report subclinical symptoms (Hillman and Lack, 2013). Insomnia disorder is characterized by complaints of dissatisfaction with sleep quality or quantity associated with difficulties initiating sleep, difficulties maintaining sleep, or early-morning awakenings with an inability to return to sleep despite adequate opportunity for sleep (American Psychiatric Association, 2013). There are wide variety of treatments for insomnia available such as pharmacotherapy, cognitive and behavioral interventions, and mindfulness-based therapies. However, many individuals with insomnia do not seek professional help, reporting preferences for non-pharmacological and self-help interventions (Holbrook et al., 2000; Vincent and Lionber, 2001; Morin et al., 2006b). Increasing attention has therefore been paid to psychological interventions such as mindfulness, which has also become widely available to the general public with the advent of smartphone applications dedicated to mindfulness practice (Plaza et al., 2013).

Mindfulness involves paying attention to one's internal experiences or surrounding environment as they occur in the present moment in a non-judgmental manner (Baer, 2003). Earlier theoretical models of insomnia focused on the role of hyperarousal, giving rise to relaxation interventions, such as progressive muscle relaxation (PMR), which aims

Abbreviations: ANOVA, analysis of variance; ISI, Insomnia Severity Index; MBSR, mindfulness-based stress reduction; NA, negative affect; PA, positive affect; PMR, progressive muscle relaxation; PSAS, Pre-Sleep Arousal Scale; PSAS (Cog), cognitive subscale of Pre-Sleep Arousal Scale; PSAS (Som), somatic subscale of Pre-Sleep Arousal Scale; SFI, sleep fragmentation index; SOL, sleep onset latency; TIB, time in bed; TST, total sleep time; TWT, total wake time; WASO, wake after sleep onset

* Corresponding author at: Turner Institute for Brain and Mental Health, School of Psychological Sciences, Monash University, 18 Innovation Walk, Clayton, VIC 3001, Australia.
E-mail address: melinda.jackson@monash.edu (M.L. Jackson).

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to reduce physiological arousal. While PMR remains an empirically supported intervention for insomnia, it is not as effective as combined cognitive and behavioral therapies, with small treatment effect sizes (Morin et al., 2006a). Models focusing on the role of cognitive arousal followed, leading to the addition of cognitive interventions aimed at modifying dysfunctional sleep-related cognitions (cognitive therapy for insomnia; Harvey, 2002). However, research has indicated that individuals with insomnia not only have a tendency to experience heightened physiological arousal and negative sleep-related cognitions (including dysfunctional beliefs about sleep, excessive worry about sleep, and selective attention to sleep-related threats) (Norell-Clarke et al., 2014), but also attempt to control their thoughts (Harvey, 2001; Lundh and Hindmarsh, 2002) and struggle to accept spontaneously occurring physiological and mental processes (Lundh, 2005). More recent theoretical models (Lundh, 2005; Ong et al., 2012) have therefore highlighted the role of metacognition in addition to hyperarousal in maintaining insomnia. From a theoretical perceptive, as compared to interventions such as PMR which focus on reducing physiological arousal, mindfulness may improve insomnia by helping individuals cultivate a more accepting and non-judgmental relationship with both physiological and mental processes.

In examining the effectiveness of mindfulness for insomnia, research has focused on face-to-face group interventions such as mindfulness-based stress reduction (Kabat-Zinn, 1982), mindfulness-based cognitive therapy for insomnia (Segal et al., 2002) and mindfulness-based therapy for insomnia (Ong et al., 2014). Both uncontrolled and controlled studies have demonstrated that these interventions have the potential to improve self-reported sleep in those with insomnia disorder (Garland et al., 2014; Gross et al., 2011; Heidenreich et al., 2006; Ong et al., 2014; Ong et al., 2008; Ong et al., 2009). Emerging research has also demonstrated improvements in pre-sleep arousal (Ong et al., 2014; Ong et al., 2008), insomnia severity (Gross et al., 2011; Ong et al., 2008), mood (Garland et al., 2014) and stress (Garland et al., 2014). However, the majority of research has been conducted in those with an insomnia disorder while less research has been conducted with individuals experiencing subclinical symptoms. Given that the rates of insomnia increase when subclinical symptoms are considered (Hillman and Lack, 2013), research investigating the effectiveness of mindfulness-based interventions in subclinical populations are also needed. Moreover, research suggests that many individuals with insomnia do not seek professional help, and instead have a tendency to use self-help strategies (Morin et al., 2006b). Despite this, few mindfulness-based applications have been empirically evaluated and no research to date has been conducted within the area of insomnia. Self-help interventions are not intended to replace face-to-face interventions, but may be effective as the initial stage in a stepped-care approach to insomnia (Ho et al., 2015; van Straten and Cuijpers, 2009) or for those with mild to moderate symptoms. This is particularly important, given the large proportion of individuals in the community with subclinical insomnia, and that there is a higher likelihood that symptoms of insomnia will progress to clinical levels if left untreated (Morin and Jarrin, 2013). Lastly, health professionals such as doctors and psychologists receive minimal education in the management of sleep disturbances during their formal training (Meltzer et al., 2009; Mindell et al., 2011; Meaklim et al., 2020), and thus evidence-based self-help programs are vital to increase access to effective insomnia treatments.

This randomized single-blind controlled pilot study aimed to examine the effectiveness of a mindfulness smartphone application for improving symptoms of insomnia in a community sample of individuals experiencing subclinical to moderate clinical symptoms of insomnia using a combination of objective and self-reported sleep measures. It was hypothesized that those participating in a smartphone-delivered mindfulness intervention would show greater improvements in objective sleep variables, self-reported sleep, insomnia severity, cognitive pre-sleep arousal, and daytime mood compared to those participating in a smartphone-delivered PMR intervention.

2. Material and method

2.1. Participants

The sample comprised 23 participants recruited via advertisements at RMIT University and Gumtree (online advertising website). Eligibility criteria were: 18 years of age and over, adequate English speaking ability, a score between 8 and 21 (inclusive) on the Insomnia Severity Index (ISI) (Morin et al., 1993) (corresponding to subclinical and clinical (moderate severity) symptoms of insomnia), little to no experience with mindfulness, and regular access to a smartphone device. Exclusion criteria were psychiatric or neurological impairment (as self-reported by participants), shift workers, high levels of psychological distress (Depression Anxiety and Stress Scales (Lovibond and Lovibond, 1995) scores $\geq$11 on the Depression scale, $\geq$15 on the Anxiety scale, and/or $\geq$13 on the Stress scale), high levels of depression (Center for Epidemiologic Studies Depression Scale (Radloff, 1977) scores $\geq$20), high risk of obstructive sleep apnea ('yes' response to three or more items on the Stop Bang Questionnaire; Chung et al., 2014), and untreated sleep disorders other than insomnia (as self-reported by participants). Participants using sleep medication or herbal supplements were asked to maintain their use and dosage throughout the study period. The study was approved by the RMIT Human Research Ethics Committee and was registered on the Australian and New Zealand Clinical Trials register (ACTRN12616000605493).

2.2. Outcome measures

2.2.1. Actigraphy

Actigraphs are wrist-worn devices that record movement data (Cheung et al., 2018). Each participant wore the GT3X watch for 14 consecutive days and nights at baseline and post-intervention to estimate sleep and wake time. Actigraphy is reliable at detecting sleep in healthy populations (Littner et al., 2003) and successfully validated against polysomnography (PSG) for insomnia (Lichstein et al., 2006; Quante et al., 2018). Actigraphy data provides the following sleep variables: a) length of time taken to fall asleep (sleep onset latency; SOL), b) time in bed (TIB), c) total sleep time (TST); d) wake after sleep onset (WASO) or total number of minutes awake each night, and e) sleep fragmentation index (SFI); an estimation of sleep disruption.

2.2.2. Insomnia severity

The ISI (Morin et al., 1993) is a 7-item self-report questionnaire that assesses subjective symptoms of insomnia and its consequences on daytime functioning and quality of life over the past month. A score of 0–7 indicates no clinically significant insomnia, 8–14 indicates subclinical insomnia, 15–21 indicates clinical insomnia (moderate severity), and 22–28 indicates clinical insomnia (severe).

2.2.3. Sleep, mood, and pre-sleep arousal diary

Self-reported sleep, daytime mood, and pre-sleep arousal were assessed using a daily diary. The sleep component of the diary measured self-reports of SOL, number of awakenings, WASO, TST, TIB, terminal wakefulness, sleep efficiency, and sleep quality. Total wake time (TWT) was chosen as the primary sleep outcome variable as it incorporates both SOL (amount of time taken to fall asleep) and WASO (amount of time spent awake during the night excluding sleep onset latency), which are the two recommended quantitative insomnia outcome measures for research (Lichstein et al., 2003), and has been used as the primary outcome in insomnia and mindfulness intervention studies (Ong et al., 2014; Ong et al., 2008).

Daytime mood was assessed using a 10-item scale comprising five positive affect (PA) and five negative affect (NA) items (van Zundert et al., 2015). Participants were asked to rate how they felt upon awakening on a 7-point Likert scale (1 = not at all to 7 = very much).

Pre-sleep arousal was measured using the Pre-Sleep Arousal Scale

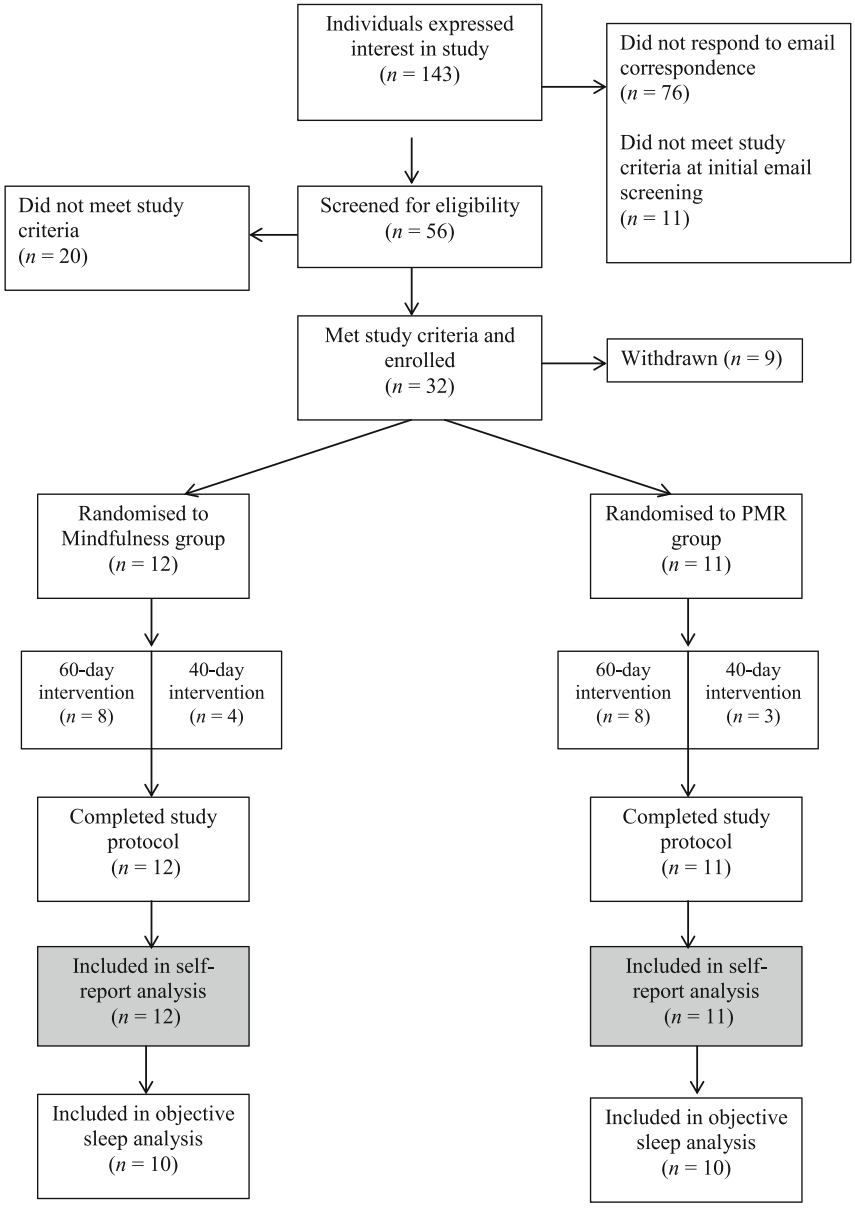

Fig. 1. The flow of participants throughout the study protocol, from the number of individuals who expressed interest in the study through to the number of participants that completed the study protocol.

(PSAS; Nicassio et al., 1985). Participants were asked to rate how intensely they experienced eight cognitive and eight somatic arousal symptoms as they attempted to fall asleep during the previous night on a 5-point Likert scale (1 = not at all to 5 = extremely).

2.2.4. Frequency of use

The number of mindfulness or PMR exercises that participants completed was assessed through usage data provided by the smartphone application company Headspace (Headspace, 2015), which measured when (date and time) participants completed an exercise and which exercise they completed.

2.3. Procedure

Those interested in the study attended a screening session at RMIT University. Those who did not meet the eligibility criteria were excluded and assisted with self-referral to an appropriate agency if requested. After providing informed consent, eligible participants were asked to complete the Sleep, Mood, and Pre-Sleep Arousal Diary for 14 days, after which participants returned to RMIT University and completed the ISI. Participants were then randomized to one of the two intervention groups stratified by age, gender, and ISI score obtained from the screening session, and were blinded to group assignment. Participants were provided with a unique code that they could use to access one of the two interventions:

1) Experimental condition: Participants in the experimental condition used the Headspace (Headspace, 2015) mindfulness smartphone application, which contained 60 guided mindfulness meditation exercises each lasting approximately 10 min. Participants were asked to use the application for 60 days, which included 30 days of the 'Foundation Pack' (core mindfulness skills) and 30 days of the 'Sleep Pack' (mindfulness skills more specifically tailored for sleeping difficulties). Due to time constraints, some participants were asked to use the application for 40 days, which included 30 days of the 'Foundation Pack' and 10 days of the 'Sleep Pack'.
2) Control condition: Participants in the control condition used a PMR smartphone application provided by Headspace (Headspace, 2015),

Table 1
Mean scores and effect sizes for objectively measured sleep outcomes for the mindfulness and PMR groups at baseline and follow-up.

Variable	Time	Mindfulness group (n = 10)	Effect size	PMR group (n = 10)	Effect size
		M (*SD*)		*M* (*SD*)	
SOL	Baseline*	10.30 (5.8)		5.70 (5.2)	
	Follow-up	3 (2.07)	1.67	5.60 (3.83)	0.02
TIB	Baseline	476.31 (161.94)		510.80 (37.56)	
	Follow-up	520.80 (87.70)	0.34	511 (48.75)	0.00
TST	Baseline	436.60 (42.28)		411 (88.81)	
	Follow-up	447.30 (87.11)	0.15	428.40 (39.59)	0.25
WASO	Baseline	70.50 (20.89)		91.00 (81.43)	
	Follow-up	64.40 (23.48)	0.27	75.90 (24.64)	0.26
SE	Baseline	83 (5)		83.40 (8.88)	
	Follow-up	86.20 (3.6)	0.73	83.80 (3.4)	0.05
SFI	Baseline	24.90 (4.7)		25.30 (8.0)	
	Follow-up	25.20 (5.5)	0.05	23.30 (7.04)	0.25

Note. SE = sleep efficiency, SFI = sleep fragmentation index, SOL = sleep onset latency, TIB = time in bed, TST = total sleep time, WASO = wake after sleep onset.

* Indicates p value < .05 between baseline values for both groups using Mann-Whitney U test.

which included 60 exercises each lasting approximately 10 min. The PMR exercises instructed participants to slow down their breathing and progressively relax the muscles in various parts of their body. PMR has been found to be an effective intervention for insomnia (Morin et al., 2006a), and as a result, this condition was considered an 'active' control condition. Participants were asked to use the application for 60 days, but due to time constraints, some participants were asked to use the application for 40 days.

Participants in both groups were asked to complete one exercise per day and instructed not to use the smartphone application as a direct method to fall asleep (i.e., at least two hours before bed). During the final 14 days of using the mindfulness or PMR smartphone application, participants were asked to complete the daily Sleep, Mood, and Pre-Sleep Arousal Diary again. At the end of this period, participants returned to RMIT University and completed the ISI.

2.4. Data analysis

One missing value was identified for self-reported TWT at follow-up. This participant was excluded pairwise from the analysis. Within self-report data, no univariate outliers (scores of ± 3.29 *SDs*) were identified. Three participants' actigraphy data did not record, leaving n = 20 in the objective sleep analyses. Actigraphy data was collected in one-minute epochs, which is the most commonly used and validated epoch length (Ancoli-Israel et al., 2015) and scored with Actilife software v6.13.4 using the Cole-Kripke algorithm. No technical issues were observed for twenty participants whose data was recorded. Mann-Whitney U tests was used to assess group differences at baseline. Effect sizes (*Cohen's d*) were calculated to examine pre-post differences in sleep variables across mindfulness and PMR groups. A series of 2 (mindfulness; PMR) x 2 (baseline; follow-up) factorial analysis of variances (ANOVAs) were conducted to determine whether there were any significant differences from baseline to follow-up between the two interventions groups for objective sleep measures, self-reported TWT, insomnia severity, cognitive pre-sleep arousal, somatic pre-sleep arousal, daytime PA, and daytime NA.

3. Results

3.1. Sample characteristics

A total of 23 participants (mean age = 36.39 ± 11.74 years, range = 22–62 years; three males) completed the study. Of these, actigraphy data was available for 20 participants (Fig. 1). Baseline ISI scores indicated that 15 participants had subclinical insomnia and eight participants had clinical insomnia of moderate severity. Seven participants indicated that they completed a post-graduate qualification, seven indicated that they completed a Bachelor's degree, four indicated that they completed some form of tertiary education, two indicated that they completed high school or equivalent, and three participants did not provide a response. Three participants were taking herbal tablets for their sleep, with one of these participants also using pharmacological sleep medication.

3.2. Frequency of use

The mindfulness group completed an average of 46.10 exercises from the Foundation and Sleep Packs (range = 11–79). One participant in the mindfulness group inadvertently completed the final 20 exercises from a different mindfulness Pack available on the Headspace application (Creativity Pack, as opposed to the Sleep Pack) and one participant replaced their final four days with exercises from the Relationship Pack. Within the PMR group, participants completed an average of 36.38 exercises (range = 7–66). Usage data was unavailable for two participants in the mindfulness group and three participants in the PMR group.

3.3. Changes in objectively measured sleep from baseline to follow-up

Modest changes were observed for sleep indices from baseline to follow-up for the combined sample (Tables 1 and 2). ANOVAs revealed significant effects of Time on SOL and WASO (n = 20). A significant Group x Time interaction was reported for SOL, with the Mindfulness group observing a greater reduction in SOL.

Within the mindfulness group, large effect size was noted for SOL (Table 3). Medium effect size was reported for sleep efficiency, and a small effect size for WASO. In contrast, PMR group reported small effect sizes for TST, WASO, and sleep fragmentation index (Table 3).

3.4. Changes in self-reported sleep from baseline to follow-up

Scores of self-reported sleep outcomes are presented in Table 3.

ANOVAs revealed no significant Group x Time interaction effects (see Table 4), however, significant main effects of Time were obtained for self-reported TWT (F(1,20) = 7.60, p = .01, η_p^2 = 0.28), ISI (F(1,21) = 38.25, p < .001, η_p^2 = 0.65), cognitive PSAS (F(1, 21) = 27.50, p < .001, η_p^2 = 0.57), daytime PA (F(1, 21) = 5.84

Table 2
Results from the series of 2 × 2 factorial analysis of variances illustrating the interaction effects between group (mindfulness group and PMR group) and time (baseline and follow-up) for all objective sleep variables.

Variable	*F*	*df*	*p*	n_p^2
SOL	6.15	1, 18	0.02	0.02
TIB	1.21	1, 18	0.28	0.33
TST	0.02	1, 18	0.86	0.46
WASO	0.03	1, 18	0.86	0.01
SE	0.46	1, 18	0.51	0.37
SFI	0.55	1, 18	0.46	0.58

Note. SE = sleep efficiency, SFI = sleep fragmentation index, SOL = sleep onset latency, TIB = time in bed, TST = total sleep time, WASO = wake after sleep onset.

Table 3
Mean scores on self-reported TWT, ISI, cognitive and somatic PSAS, and daytime PA and NA for the mindfulness and PMR groups at baseline and follow-up.

Variable	Time	Mindfulness group (n = 12)		Effect size	PMR group (n = 11)		Effect size
		M (*SD*)	95% CI		*M* (*SD*)	95% CI	
TWT	Baseline	68.10 (44.77)	[44.70, 91.50]		46.42 (30.09)*	[20.79, 72.05]*	
	Follow-up	51.01 (21.24)	[38.72, 63.30]	0.48	25.22 (19.34)*	[11.76, 38.67]*	0.83
ISI	Baseline	13.33 (3.47)	[11.62, 15.05]		13.91 (1.97)	[12.12, 15.70]	
	Follow-up	7.67 (3.28)	[5.47, 9.86]	1.61	7.73 (4.03)	[5.43, 10.02]	1.97
PSAS (Cog)	Baseline***	15.58 (4.17)	[0.06, 0.08]*		15.25 (4.11)	[0.06, 0.08]**	
	Follow-up	12.46 (1.66)	[0.07, 0.09]*	0.98	12.45 (3.25)	[0.07, 0.10]**	0.74
PSAS (Som)	Baseline	10.60 (1.41)	[9.65, 11.54]		10.42 (1.72)	[9.44, 11.41]	
	Follow-up	9.27 (1.01)	[8.31, 10.24]	1.08	10.31 (2.07)	[9.31, 11.32]	0.05
Daytime PA	Baseline	16.44 (5.66)	[13.20, 19.69]		16.30 (5.12)	[12.90, 19.69]	
	Follow-up	17.60 (5.29)	[14.08, 21.11]	0.21	19.13 (6.43)	[14.50, 22.80]	0.48
Daytime NA	Baseline	7.66 (2.05)	[0.12, 0.16]**		8.37 (2.33)	[0.11, 0.15]**	
	Follow-up	6.61 (1.45)	[0.14, 0.18]**	0.59	7.19 (2.68)	[0.13, 0.17]**	0.46

Note. TWT = total wake time, ISI = Insomnia Severity Index, PSAS (Cog) = cognitive subscale of Pre-Sleep Arousal Scale, PSAS (Som) = somatic subscale of Pre-Sleep Arousal Scale, PA = positive affect, NA = negative affect, PMR = progressive muscle relaxation.
* n = 10.
** Obtained following reciprocal transformation.
*** Indicates p value < .05 between baseline values for both groups on chi-square test.

Table 4
Results from the series of 2 × 2 factorial analysis of variances illustrating the interaction effects between group (mindfulness group and PMR group) and time (baseline and follow-up) for all self-reported outcome variables.

Variable	*F*	*df*	*p*	η_p^2
TWT	0.09	1, 20	.77	0.005
ISI	0.07	1, 21	.79	0.003
PSAS (Cog)*	0.14	1, 21	.71	0.007
PSAS (Som)	2.83	1, 21	.12	0.12
Daytime PA	1.04	1, 21	.32	0.05
Daytime NA*	0.16	1, 21	.69	0.008

Note. TWT = total wake time, ISI = Insomnia Severity Index, PSAS (Cog) = reciprocal of cognitive subscale of Pre-Sleep Arousal Scale, PSAS (Som) = somatic subscale of Pre-Sleep Arousal Scale, PA = positive affect, NA = reciprocal of negative affect, PMR = progressive muscle relaxation.
* Reciprocal transformation.

p = .03 η_p^2 = 0.22), and the reciprocal of daytime NA (F(1, 21) = 8.83, p = .01, η_p^2 = 0.30). No significant main effect of Time for somatic PSAS was found (p = .06). In particular, the mindfulness group reported large effect sizes for both cognitive and somatic pre-sleep arousal.

3.5. Changes in insomnia severity from baseline to follow-up

Fig. 2 displays changes in insomnia severity category from pre to post intervention for each participant. Of the 15 participants who had subclinical insomnia at baseline, eight remained in the subclinical range and seven participants had no clinically significant symptoms of insomnia at follow-up. Of the eight participants who had clinical insomnia of moderate severity at baseline, three participants were in the subclinical range and five participants had no clinically significant symptoms of insomnia at follow-up. Overall, a large effect size was observed for scores on the ISI (*Cohen's d* = 1.86).

4. Discussion

This study aimed to examine the effectiveness of a mindfulness smartphone application for improving objective sleep variables, self-reported sleep, insomnia severity, pre-sleep arousal, and daytime mood in adults with symptoms of insomnia. It was hypothesized that participants in the mindfulness group would show enhanced improvements in sleep outcomes compared to those in the PMR group. While

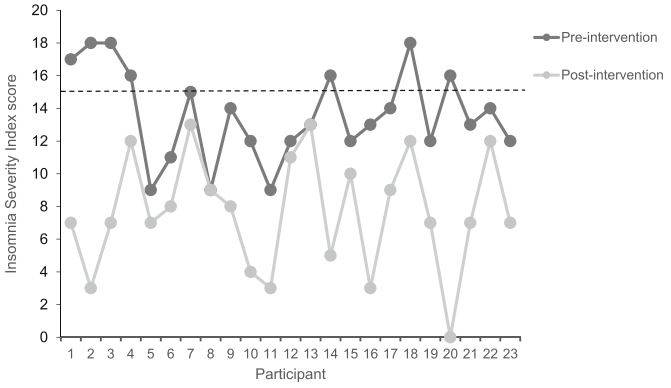

Fig. 2. Changes in scores on insomnia severity index for all 23 participants from baseline to post-intervention. A score of 15 and over indicates significant moderate to severe insomnia, indicated by the dashed line.

participants in the mindfulness group showed lower SOL, no other significant group interactions were observed. Objective sleep variables such as WASO significantly improved for the overall group. Significant improvements were also noted for all self-reported outcome variables (TWT, insomnia severity, cognitive symptoms of pre-sleep arousal, and daytime PA and NA) except for somatic symptoms of pre-sleep arousal, from baseline to follow-up across both intervention groups. These findings suggest that a digital mindfulness intervention was superior to a PMR intervention for reducing SOL, with smaller improvements in WASO, TWT, and cognitive symptoms of pre-sleep arousal, and for improving insomnia severity and daytime mood for both interventions over time.

The finding that objectively-measured SOL in the mindfulness group was significantly reduced compared to the PMR group at follow-up is consistent with studies examining the effectiveness of face-to-face group mindfulness-based interventions for insomnia (Gross et al., 2011; Garland et al., 2014; Ong et al., 2014). Medium effect size was also observed for sleep efficiency in the current study. Face-to-face mindfulness meditation programs, such as mindfulness-based stress reduction (MBSR), have also been shown to provide significant improvement in sleep efficiency and sleep onset in comparison to other treatment groups, such as pharmacotherapy, in patients with chronic insomnia (e.g., Gross et al., 2011; Taylor et al., 2015).

Group differences on the self-reported sleep outcomes were less pronounced, with both groups reporting improvements over time. The

observed improvements in self-reported TWT, with moderate to large effect sizes, is consistent with previous research reporting improvements in self-reported SOL and WASO following mindfulness-based group therapy (Gross et al., 2011; Garland et al., 2014; Heidenreich et al., 2006; Ong et al., 2014) and therapist-delivered CBT-I (Trauer et al., 2015). For example, a meta-analysis of studies evaluating face-to-face CBT-I reported a reduction in SOL of 19-min and WASO of 26 min compared to inactive control groups, with a large effect size (Trauer et al., 2015). Thus we anticipate improvements in insomnia from digital mindfulness training to be significant but of a slightly smaller magnitude to CBT-I. However, with the ease of access that the population has to digital mindfulness interventions, these small improvements in insomnia on a large scale could make a significant positive impact to many people's sleep.

The improvements in cognitive pre-sleep arousal are consistent with theoretical models of insomnia and previous intervention research (Ong et al., 2014; Ong et al., 2008; Ong et al., 2009). Aside from MBSR, other treatments such as mindfulness-based therapy for insomnia (MBT-i) have also been shown to improve sleep efficiency and sleep-related arousal (Ong et al., 2008). Finally, the improvements in daytime positive and negative affect are consistent with research by Garland et al. (2014) who found significant improvements in mood and stress in patients with insomnia and cancer following a mindfulness-based stress reduction program. Previous focus groups indicate that mindfulness can motivate participants to adopt healthy sleep lifestyles and may be applicable to aspects beyond sleep (Hubbling et al., 2014). This preliminary study indicates that mindfulness-based smartphone applications can provide similar benefits for different aspects of sleep and wellbeing in individuals with subclinical to moderate symptoms of insomnia. Therefore, such applications may be an effective alternative for individuals with subclinical or milder forms of insomnia, or patients who are unable to access face-to-face interventions.

While overall changes were observed in sleep onset latency, the authors noted disagreements within SOL as recorded by actigraphy and reported in participants' sleep diaries. This may be due to the fact that actigraphy can underestimate sleep onset in comparison to polysomnography as it is cannot discriminate between motionless wake from sleep (Tonetti et al., 2008); although it is not feasible to use polysomnography in long-term studies. Actigraphy is a valid instrument for TST, WASO and SE in adults, but has low specificity for wake episodes (Quante et al., 2018). Future studies should consider employing more robust algorithms or high-specificity criteria. The actigraphy data obtained from the current sample was atypical to what would be observed in an insomnia disorder sample. It should be noted that the inclusion of individuals with subclinical symptoms (i.e., ISI 8–14) may explain this discrepancy. The lack of clinically significant objective sleep onset difficulties or poor sleep efficiency at baseline may have tempered our results, as many participants may not have much room for improvement in these outcomes. Despite this, we did see an improvement in SOL in the mindfulness group. The lack of improvement in the somatic symptoms of pre-sleep arousal is worth noting. Although previous research has found improvements in pre-sleep arousal using the PSAS following group mindfulness-based interventions, these studies did not examine cognitive and somatic pre-sleep arousal as separate constructs (Ong et al., 2014; Ong et al., 2008). The lack of improvement in somatic pre-sleep arousal may also be due to the fact that participants in the PMR group were explicitly instructed to not use the smartphone application as a direct method to fall asleep (i.e., not directly before bed) so as to create as little variability between the two groups as possible, which may have reduced the expected relaxing effects of PMR. It is possible that improvements in insomnia may be mediated by changes in cognitive arousal, rather than a reduction in somatic symptoms per se.

The finding that the mindfulness group did not show enhanced improvements in several sleep outcomes over time compared to the PMR group suggests that both interventions may have the potential to improve symptoms of insomnia. While PMR did not produce any significant changes in objective sleep indices, small effect sizes were observed for TST, WASO, and sleep fragmentation. Therefore, there may be benefits to utilizing PMR smartphone applications in promoting better sleep health. Future studies should access its usability within larger samples.

The current study lacked a no-treatment control group and as a result, the possible contribution of other factors such as time and the use of self-monitoring need to be considered. It therefore cannot be concluded that mindfulness and PMR smartphone applications are effective in improving symptoms of insomnia over and above those undergoing no treatment. Further, it is still unclear how app-based mindfulness programs may compare to face-to-face mindfulness interventions in terms of efficacy. The limitations of a small sample size should also be noted. Larger controlled studies comparing mindfulness smartphone applications to no intervention and treatment-as-usual (including pharmacology and face-to-face interventions) are therefore needed. Future studies should consider comparing mindfulness applications to face-to-face interventions to determine both feasibility and efficacy.

5. Conclusion

The current research found significant improvements in insomnia symptoms by using an accessible smartphone application. Both mindfulness and PMR were helpful in improving insomnia symptoms, with mindfulness found to be slightly superior in reducing sleep onset latency. Digital therapeutics are widely disseminable, thus there is value in further research exploring the efficacy of smartphone applications as a self-help option for the large proportion of the community experiencing symptoms of insomnia.

Declaration of competing interest

The research was supported by Headspace. Headspace had no role in study design, analysis or manuscript preparation. The authors have no conflicts of interest to declare.

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