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RESEARCH ARTICLE

Effects of mindfulness-based therapy for insomnia and a sleep hygiene/exercise programme on subjective-objective sleep discrepancy in older adults with sleep disturbances: Exploratory secondary analysis of a randomised clinical trial

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Summary

Older adults with poor sleep tend to show a discrepancy between objective and self-reported sleep parameters, which can trigger a vicious cycle that worsens their sleep complaints. Cognitive-behavioural therapy can reduce this discrepancy, but alternative behavioural therapies remain untested. The present exploratory study aimed to investigate the effects of mindfulness-based therapy for insomnia (MBTI) on reducing sleep discrepancies in comparison with a sleep hygiene, education, and exercise programme (SHEEP). Older adults were randomly allocated into the mindfulness-based therapy for insomnia group ($n = 55$) or the sleep hygiene, education, and exercise programme group ($n = 58$). Subjective and objective sleep parameters were measured using sleep diaries, polysomnography (PSG), and actigraphy. Sleep discrepancies were calculated using the Bland–Altman method for sleep onset latency (SOL) and wake after sleep onset (WASO). Additionally, correlations between the change in sleep discrepancies and the change in subjective sleep quality and trait mindfulness were measured within each group. Sleep onset latency discrepancy measured by polysomnography and actigraphy decreased significantly after the MBTI and SHEEP interventions. In contrast, there was no significant change in wake after sleep onset discrepancy in either group. The change in sleep onset latency discrepancy was correlated with the change in insomnia symptoms and objectively measured trait mindfulness. Mindfulness-based therapy for insomnia was effective in reducing sleep onset latency discrepancies and improving sleep perception in older adults with sleep disturbances, which in turn drove an improvement in sleep quality and insomnia symptoms. Increases in trait mindfulness may have been an important mechanism in improving sleep perception in the mindfulness-based therapy for insomnia group.

KEYWORDS
actigraphy, Bland–Altman plots, polysomnography, sleep diaries, sleep discrepancy

1 | INTRODUCTION

Ageing is associated with an increase in sleep disturbances and poor sleep quality. Around 65% of older adults report sleep problems, including light and fragmented sleep, early morning awakenings, or excessive daytime sleepiness (McCrae et al., 2009). This may be due to several ageing-related factors such as the presence of comorbidities (Wang et al., 2017), changes in sleep architecture

(Taillard et al., 2021), delayed and advanced sleep phases (Ando et al., 2002), and disturbed cognitive functions (Dzierzewski et al., 2010). It is well known that sleep disturbances have high personal, health, and social costs (Foley et al., 1995; Ozminkowski et al., 2007; Shi et al., 2018). Disturbed sleep in older adults correlates with daytime consequences including increased depression symptoms, cognitive impairments, and functional limitations (Buysse et al., 2005; Nebes et al., 2009). Therefore, improving sleep quality is considered an effective target for improving the quality of life in older adults.

The perception of poor sleep is one of the key characteristics of insomnia. A body of clinical studies has demonstrated that poor sleepers commonly report a discrepancy between their self-reported estimation of sleep and objective measures such as polysomnography (PSG) or actigraphy (Kay et al., 2015; Williams et al., 2013). Specifically, poor sleepers tend to overestimate the total wake time during the night, which in turn exacerbates negative thoughts and dysfunctional beliefs relating to their sleep habits (Harvey & Tang, 2012; Mercer et al., 2002). Misperception has also been observed for other sleep parameters, including sleep onset latency (SOL), total sleep time (TST), and sleep efficiency (SE) (Kay et al., 2013; Kay et al., 2015). The prevalence of subjective-objective sleep discrepancy in insomnia sufferers ranges from 9.2% to 50%, depending on the diagnostic criteria used (Edinger & Krystal, 2003). In particular, sleep discrepancies are noted to be greater in older adults compared with younger individuals (Kay et al., 2015, 2013; Williams et al., 2013), suggesting that sleep discrepancy may play a role in the high rates of late-life insomnia. However, the mechanism of sleep discrepancy remains understudied amongst older adults with sleep disturbances (Williams et al., 2013).

The mismatch between self-reported and objective sleep measures has several implications for insomnia diagnosis and treatment. Studies have shown that sleep misperception in patients with insomnia leads to negative thoughts and worries about not getting sufficient sleep, which consequently leads to anxiety. Increased anxiety about sleep further hinders the ability to sleep and adversely affects patients' perceptions of daytime functioning. This creates a vicious cycle where sleep misperception aggravates insomnia symptoms (Harvey & Tang, 2012; Mercer et al., 2002). Therefore, understanding the relationship between sleep discrepancy and insomnia is an important area of study.

At present, cognitive-behavioural therapy for insomnia (CBTi) is the frontline treatment for insomnia disorder (Qaseem et al., 2016). There is a large body of research reporting that CBTi has medium to large effects on improving sleep measures such as SOL, WASO, and SE (Schutte-Rodin et al., 2008). Additionally, some studies have reported a reduction in sleep discrepancy and improvement in sleep quality after five to eight sessions of CBTi (Kay et al., 2015; Okajima et al., 2011). Although CBTi is the recommended treatment for insomnia, it can be expensive, and the dropout rate as well as the non-response rate are relatively high (Fernandez et al., 2015). Moreover, limited access to experienced CBTi providers remains a barrier in its implementation (Koffel et al., 2018). Therefore, it is important to establish alternative or complementary therapies as second-line treatment options to reduce sleep discrepancies, which should in turn drive improvement in sleep quality in patients with sleep disturbances.

Since the introduction of the mindfulness-based stress reduction (MBSR) programme – developed by Jon Kabat-Zinn – there has been extensive interest in mindfulness to improve health and well-being (Kabat-Zinn, 1990). In general, mindfulness-based approaches have proven to improve sleep quality both in-person (Black et al., 2015) or administered as a digital programme (Kennett et al., 2021). In the past decade, a body of work has been published supporting the role of mindfulness in alleviating insomnia symptoms (Ong et al., 2014; Perini et al., 2021). Recent meta-analyses of randomised control trials (RCTs) have also concluded that non-sleep-targeted mindfulness training significantly improves sleep quality in adults with chronic insomnia or other sleep disorders (Gong et al., 2016; Rusch et al., 2019).

More recently, mindfulness-based therapy for insomnia (MBTI) has been developed and tested as a sleep-targeted mindfulness-based intervention for patients with sleep disturbances (Ong et al., 2012; Ong & Smith, 2017). It consists of mindful practices and inquiry drawn from MBSR with behavioural strategies used in CBTi. Unlike CBTi, MBTI focusses on metacognition by increasing awareness of the psychophysiological states that are present when experiencing insomnia symptoms and instructing patients on how to adopt a more flexible attitude towards these experiences (Jankowski & Holas, 2014; Ong et al., 2012). Strengthening metacognition has been shown to improve positive mood states, decrease distractive and ruminative thoughts, balance appraisals, and to reduce sleep-related arousal, which together may facilitate sleep (Desbordes et al., 2012; Hassirim et al., 2019; Jain et al., 2007). Whilst MBTI has been shown to increase sleep duration and quality (Ong et al., 2014; Perini et al., 2021), no prior study has reported on the changes in subjective-objective sleep discrepancies associated with MBTI.

The current study is an exploratory analysis of data collected from a previously conducted randomised controlled trial of MBTI for older adults with sleep disturbances (Perini et al., 2021). The primary aim of the present analysis is to assess the change in subjective-objective discrepancies in sleep measures (SOL and WASO) after the interventions. Additionally, we aimed to explore how the change in these discrepancies correlated with the change in self-reported sleep quality and changes in trait mindfulness.

2 | METHODS

We conducted secondary analyses on data from a randomised controlled trial comparing the effects of mindfulness-based therapy for insomnia (MBTI) against a sleep hygiene, education, and exercise programme (SHEEP) in a group of older adults. This trial was registered on ClinicalTrials.gov with identifier NCT03677726. All study procedures comply with the Helsinki Declaration of 1975 (revised in 2008) and with the ethical standards on human experimentation. The SingHealth Clinical Institution Review Board (identifier 2017–2830) and the Institutional Review Board of the National University of Singapore approval were obtained prior to participants' recruitment. All subjects provided written informed consent before enrolment.

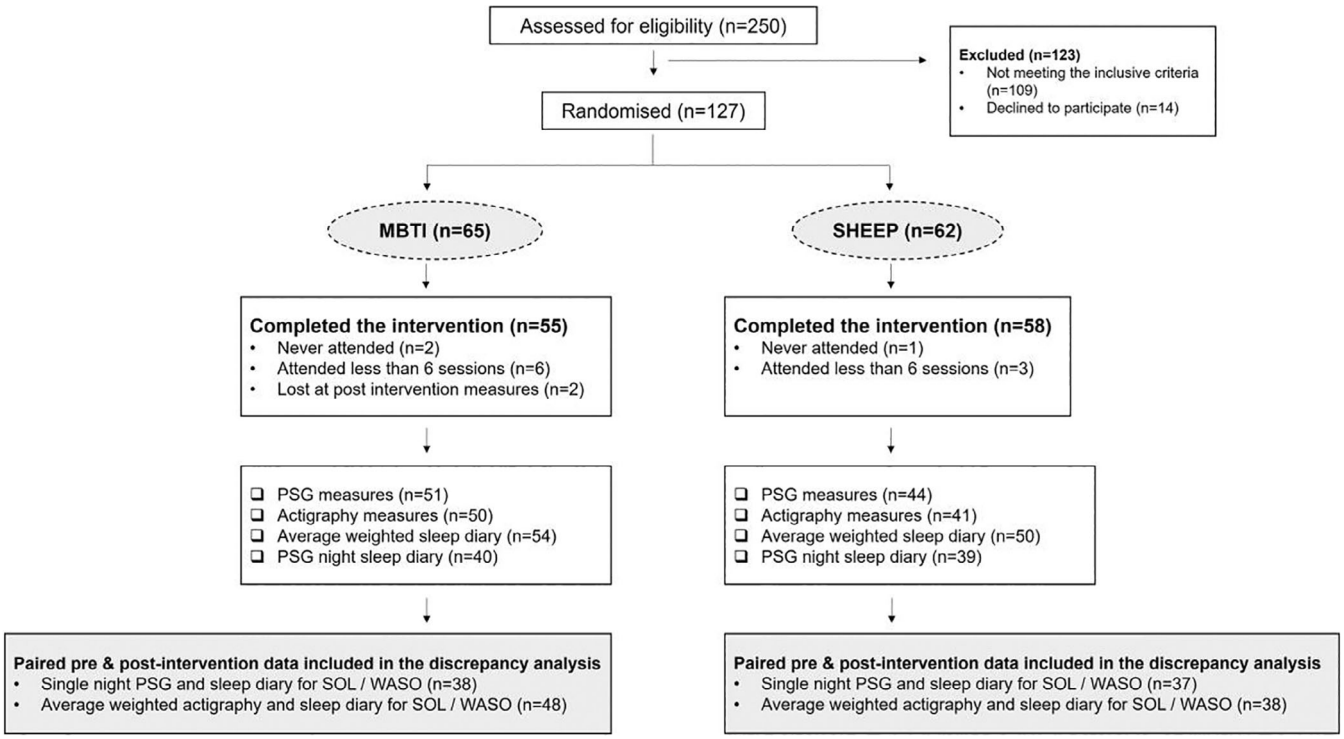

FIGURE 1 CONSORT chart showing the sample analysed in this study. MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; PSG, polysomnography; SOL, sleep onset latency; WASO, wake-time after sleep onset

2.1 | Participants' characteristics and interventions

A total of 127 older adults (mean age = 60.9 ± 6.4) were randomised to receive either MBTI ($n = 65$) or SHEEP ($n = 62$), of which 55 participants from the MBTI group and 58 participants from the SHEEP group completed the intervention. The CONSORT diagram for the sample analysed in this paper is presented in Figure 1. Inclusion criteria for this clinical trial were: age 50–80 years, no cognitive impairment assessed by (a) mini-mental state examination (Folstein et al., 1975) score ≥ 26, and (b) Montreal cognitive assessment (Nasreddine et al., 2005) score ≥ 23, self-reported sleep problems over the past month, defined as a Pittsburgh sleep quality index (PSQI) (Buysse et al., 1989) score ≥ 5, and at least one of the following as determined by the same scale: (i) average wakefulness after sleep onset (WASO) of >30 min ($n = 73$), (ii) average reported sleep onset latency (SOL) of >30 min ($n = 63$), (iii) average total sleep time (TST) of <6.5 h ($n = 69$). Participants were excluded from the study if they reported at screening the presence of major neurological or psychiatric disorders (or reported suicidal ideation >1 in the Beck's depression inventory), ongoing long-term use of sleep medications, or if they could not provide independent consent. Participants included in the study had never attended a mindfulness-based intervention (Perini et al., 2021).

Both MBTI and SHEEP programmes contained eight weekly face-to-face sessions each lasting 2 h. Interventions were matched for the time spent with instructors, amount of homework, and general content. Subjects were considered to have completed their intervention if they attended at least six out of the eight sessions. Full details of the study protocol, interventions, and findings from the primary analyses have been published elsewhere (Perini et al., 2021). We did not plan to investigate the subjective-objective sleep discrepancy at the time of the trial registration, and have thus framed the results obtained here as exploratory throughout.

2.2 | Outcome measures

2.2.1 | Objective sleep variables

Objective sleep outcomes were measured using actigraphy and polysomnography collected at baseline and post-intervention with blinded assessments. Actigraphy was measured using a Phillips Actiwatch-2 or Actiwatch-Spectrum (Philips Respironics Inc., Pittsburgh, PA). Most of the participants wore a wrist actigraph for more than 7 consecutive days/nights at each assessment time point. Sleep variables were calculated automatically using Actiware software (version 6.0.2) on a medium setting with a 10 minute sleep and wake window. Weekday and weekend sleep variables measured by actigraphy were consolidated using a weighted (5:2) average. The scoring protocol is described in detail in Perini et al. (2021).

A single night of polysomnography data was collected using SOMNOtouch RESP recorders (SOMNOmedics GrmbH, Randersacker, Germany) in participants' homes. Sleep recordings were scored by two trained staff members. Two-thirds of all available nights were randomly selected to be scored by either staff member, allowing for one-third of all data to be double scored to calculate inter-rater reliability (Perini et al., 2021).

We computed sleep onset latency (SOL_{PSG} or SOL_{Acti}) determined by the first non-wake and non-N1 sleep epoch, and wake after sleep onset ($WASO_{PSG}$ or $WASO_{Acti}$) measured as the summation of all waking time

TABLE 1 Means of objective and self-reported SOL and WASO for both groups at baseline and post-treatment

Variable		MBTI				SHEEP				p value for baseline group comparison
		Mean of pre (SD) min	Mean of post (SD) min	p value	Cohen's d	Mean of pre (SD) min	Mean of post (SD) min	p value	Cohen's d	
SOL	PSG	19.11 (17.57)	14.84 (10.19)	0.126	−0.151	16.07 (11.71)	14.90 (12.37)	0.141	−0.157	0.48
	Actigraphy	18.66 (14.63)	14.36 (9.06)	0.245	−0.116	20.93 (20.81)	16.88 (11.77)	0.791	−0.029	0.41
	Diary average	30.64 (19.36)	21.29 (12.43)	**<0.001**	**−0.350**	38.43 (24.17)	23.73 (17.28)	**<0.001**	**−0.413**	0.97
	Diary 1 night	46.00 (40.17)	28.39 (26.16)	**0.026**	**−0.249**	41.23 (42.23)	27.57 (29.89)	0.100	−0.186	0.19
WASO	PSG	80.61 (51.14)	64.74 (41.25)	**0.016**	**−0.248**	69.59 (49.58)	64.84 (48.43)	0.125	−0.160	0.33
	Actigraphy	72.36 (33.89)	63.26 (22.41)	**0.005**	**−0.282**	65.28 (24.89)	71.25 (27.09)	0.763	−0.032	0.25
	Diary average	36.81 (36.71)	23.82 (23.10)	**0.007**	**−0.263**	36.26 (34.37)	23.04 (18.18)	**<0.001**	**−0.372**	0.63
	Diary 1 night	40.45 (43.13)	32.45 (35.47)	0.056	−0.186	45.69 (59.70)	32.92 (31.45)	**0.043**	**−0.229**	0.78

Means of objective and self-reported SOL and WASO in minutes measured by polysomnography, actigraphy, diary average, and diary 1 night for the MBTI and SHEEP groups at the baseline and post-treatment.
Bold values denote statistical significance at the $p < 0.05$, < 0.01, or < 0.001 levels.
MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; SOL, sleep onset latency; WASO, wake-time after sleep onset; PSG, polysomnography; SD, standard deviation.

scored between SOL and the final morning awakening, as the primary outcome variables when analysing polysomnography and actigraphy data.

2.2.2 | Self-reported sleep variables

The self-reported outcomes for our study were variables extracted from sleep diaries, and scores on the insomnia severity index (ISI) and Pittsburgh sleep quality index (PSQI). For sleep diaries, the participants were instructed to complete daily sleep diaries for at least 7 consecutive days/nights coinciding with the periods of the actigraphic recording (Diary_average or $SOL/WASO_{D\_avg}$) and polysomnography recording (Diary_1night or $SOL/WASO_{D\_1night}$). Sleep diaries contained nine items considered by the consensus sleep diary (CSD) workgroup and the 2005 conference participants to represent the most critical parameters (Carney et al., 2012). These items provided the following metrics: (i) sleep onset latency (SOL) – the time from initial lights out until sleep onset; and (ii) wake time after sleep onset (WASO) – the time spent awake after initial sleep onset until the last awakening.

For sleep outcomes, the severity of insomnia symptoms was assessed by ISI (Morin et al., 2011) and the global sleep quality was assessed using PSQI (Buysse et al., 1989).

2.2.3 | Subjective-objective sleep discrepancy

The discrepancy between self-reported and objective sleep measures was computed by subtracting diary-reported SOL/WASO from the appropriately paired periods of objectively assessed SOL/WASO (Dzierzewski et al., 2019; Williams et al., 2013). Four discrepancy variables were created: discrepancy between SOL estimation with polysomnography ($SOL_{PSG\_discrep}$) and actigraphy ($SOL_{Acti\_discrep}$), and discrepancy between WASO estimation with PSG ($WASO_{PSG\_discrep}$) and actigraphy ($WASO_{Acti\_discrep}$). For these calculations, we used self-reported diary data that corresponded with the respective period during which the objective data were collected. Positive discrepancy scores reflect underestimation, and negative scores reflect overestimation, compared with objective findings (Manconi et al., 2010). Subjects were only included in the analyses if a complete sleep diary and matching objective data (polysomnography or actigraphy) at pre-and post-treatment were available.

2.2.4 | Mindfulness measures

Self-reported trait mindfulness was measured using the five facet mindfulness questionnaire (FFMQ), which assesses five facets of mindfulness: observing, describing, acting with awareness, non-judgement, and non-reactivity (Baer et al., 2006). This questionnaire displays adequate psychometric properties in terms of internal consistency, factor structure, test–retest reliability, convergent validity, and responsiveness to training (Baer et al., 2008). Previous studies reported that the reliability coefficients (Cronbach's alphas) for the FFMQ-39 subscales range from 0.82 to 0.93 (Williams et al., 2014).

TABLE 2 Means of subjective-objective discrepancy in SOL and WASO for both groups at baseline and post-treatment

Variable		Pre-intervention		Post-intervention		Discrepancy difference (min)	*p* value	Cohen's d	*p* value for baseline group comparison
		Discrepancy (min)	LOA (upper, lower)	Discrepancy (min)	LOA (upper, lower)				
$SOL_{PSG\_discrep}$	MBTI	**−31.91**	(65.57, −129.39)	**−13.67**	(38.38, −65.74)	18.24	0.036	**−0.240**	0.98
	SHEEP	**−31.63**	(73.12, −136.40)	**−23.68**	(73.97, −121.33)	7.95	0.096	−0.193	
$WASO_{PSG\_discrep}$	MBTI	**46.78**	(150.5, −56.93)	**31.23**	(112.71, −50.24)	15.55	0.315	0.118	0.13
	SHEEP	**33.27**	(135.37, −68.82)	**40.38**	(141.32, −60.55)	−7.11	0.353	−0.106	
$SOL_{Acti\_discrep}$	BTI	**−17.50**	(26.77, −61.79)	**−8.87**	(16.45, −34.20)	8.63	0.012	**−0.256**	0.61
	SHEEP	**−17.23**	(46.00, −80.48)	**−5.00**	(30.80, −40.81)	12.23	<0.001	**−0.376**	
$WASO_{Acti\_discrep}$	MBTI	**34.02**	(124.54, −56.48)	**35.89**	(91.00, −19.21)	−1.87	0.566	−0.059	0.51
	SHEEP	**32.23**	(102.24, −37.78)	**45.89**	(105.11, −13.32)	−13.66	<0.001	**−0.401**	

Positive values of discrepancy indicate that subjects underestimated the sleep measures, whilst negative values denote that subjects overestimated the sleep measures, compared with polysomnography or actigraphy findings. Bold values denote statistical significance at the $p < 0.05$, < 0.01, or < 0.001 levels.

$SOL_{PSG\_discrep}$, the discrepancy between PSG-recorded and self-reported sleep onset latency; $WASO_{PSG\_discrep}$, the discrepancy between PSG-recorded and self-reported wake after sleep onset; $SOL_{Acti\_discrep}$, the discrepancy between actigraphy-recorded and self-reported sleep onset latency; $WASO_{Acti\_discrep}$, the discrepancy between actigraphy-recorded and self-reported wake after sleep onset; MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; LOA, limits of agreements.

We used the breath counting task (BCT) accuracy as a behavioural index of mindfulness and meta-awareness (Levinson et al., 2014; Wong et al., 2018). During the BCT, participants were asked to press on the *Left Arrow* key with breaths 1–8, the *Right Arrow* key with breath nine, and the *Space* key to restart the count from one if they lost track of the counts. Accuracy was computed as the percentage of cycles in which participants correctly pressed the *Right Arrow* key on the 9th breath. Full details of the scoring protocol have been reported in (Lim & Doshi, 2022). All self-reported and objective outcomes were evaluated at pre-and post-interventions.

2.3 | Statistical analyses

The means of subjective-objective sleep discrepancy pre- and post-intervention for SOL and WASO were calculated for MBTI and SHEEP participants separately according to the Bland and Altman method (Bland & Altman, 1986). Differences were calculated by subtracting the sleep parameters determined by sleep diaries from polysomnography or actigraphy for each participant. Some participants had a very large discrepancy score (>3 SD from the mean) compared with the rest of the group, and therefore were considered outliers and excluded from the analysis. For completeness, the primary analysis with these participants included is reported in Table S1 and Figures S1, S2.

We analysed the discrepancy in SOL and WASO using 2×2 repeated measures analysis of variance (rmANOVA) with time (pre/-post) as a within-subjects factor and group (MBTI/SHEEP) as a between-subjects factor. Post hoc analyses were further conducted using the Wilcoxon signed-rank test with Bonferroni correction ($\alpha = 0.0125$) to measure the differences in discrepancy between the baseline and post-treatment. Bland–Altman plots were generated to illustrate the mean of the discrepancy, the lower limits, and the upper limits of agreement (LOA) (mean difference ± 1.96 SD).

The remaining sleep and mindfulness variables were analysed using repeated-measures ANOVA with time (pre/post) as a within-subjects factor and group (MBTI/SHEEP) as a between-subjects factor. Following a significant effect in the rmANOVA, Tukey post hoc analyses were further conducted for pairwise comparisons. Finally, we used Pearson's correlation to measure the association between the change in discrepancies in SOL estimation and the change in ISI, PSQI, FFMQ, and BCT accuracy. Comparisons were considered statistically significant at $\alpha = 0.05$.

Effect sizes for comparisons were estimated using Cohen's d. All statistical analyses, scatter- and Bland–Altman plots were conducted with IBM SPSS Statistics for Windows Version 26 (IBM Corp., Armonk, NY).

3 | RESULTS

Baseline variables

There were no significant differences in baseline variables between the groups (Tables 1 and 2). At baseline, our participants tended to overestimate sleep onset latency and to underestimate wake time

after sleep onset (Maric et al., 2019), although in all cases the zero point (no discrepancy) still fell within the limits of agreement.

Means of objective and self-reported estimation of **SOL** and **WASO** for **MBTI** and **SHEEP** groups

We first examined whether self-reported and objective sleep outcomes (SOL and WASO) were significantly affected by the two interventions. Some of these results have been reported previously using intent-to-treat analysis (Perini et al., 2021), but we show them here as there are differences between that report and the results from completers in this subsample.

For sleep onset latency, we found a main effect of time only in SOL_{D_avg} ($p < 0.001$) and SOL_{D_1night} ($p = 0.012$). None of the time by group interactions were significant. For wake time after sleep onset, we found a main effect of time in $WASO_{PSG}$ ($p = 0.010$), $WASO_{Acti}$ ($p = 0.048$), $WASO_{D\_avg}$ ($p < 0.001$), and $WASO_{D\_1night}$ ($p = 0.023$). The time by group interaction was only significant in $WASO_{Acti}$ ($p = 0.015$) (Table S2).

Post hoc analyses showed that the MBTI and SHEEP significantly reduced self-reported sleep onset latency (MBTI: SOL_{D_avg} $d = -0.350$; SOL_{D_1night} $d = -0.249$; SHEEP: SOL_{D_avg} $d = -0.413$). MBTI significantly reduced self-reported wake time after sleep onset ($WASO_{D\_avg}$: $d = -0.263$) as well as objectively assessed WASO ($WASO_{PSG}$: $d = -0.248$; $WASO_{Acti}$: $d = -0.282$). SHEEP only significantly reduced self-reported WASO ($WASO_{D\_avg}$: $d = -0.372$; $WASO_{D\_1night}$: $d = -0.229$). Both treatments' effects were larger for self-report measures compared with objective measures of sleep (Table 1).

The subjective-objective sleep discrepancy in **SOL** and **WASO** for both groups

Subjective-objective sleep discrepancies in sleep onset latency and wake time after sleep onset were calculated using the Bland and Altman method. For sleep onset latency, we found a main effect of time on polysomnography and actigraphy discrepancy [$SOL_{PSG\_discrep}$: $p = 0.016$; $SOL_{Acti\_discrep}$: $p < 0.001$], with less discrepancy reported post-intervention. None of the time by group interactions were significant. For wake time after sleep onset, we found no main effect of time on polysomnography discrepancy ($p = 0.81$) and no time by group interactions ($p = 0.21$). We found a main effect of time in actigraphy discrepancy ($p < 0.001$) with significant time by group

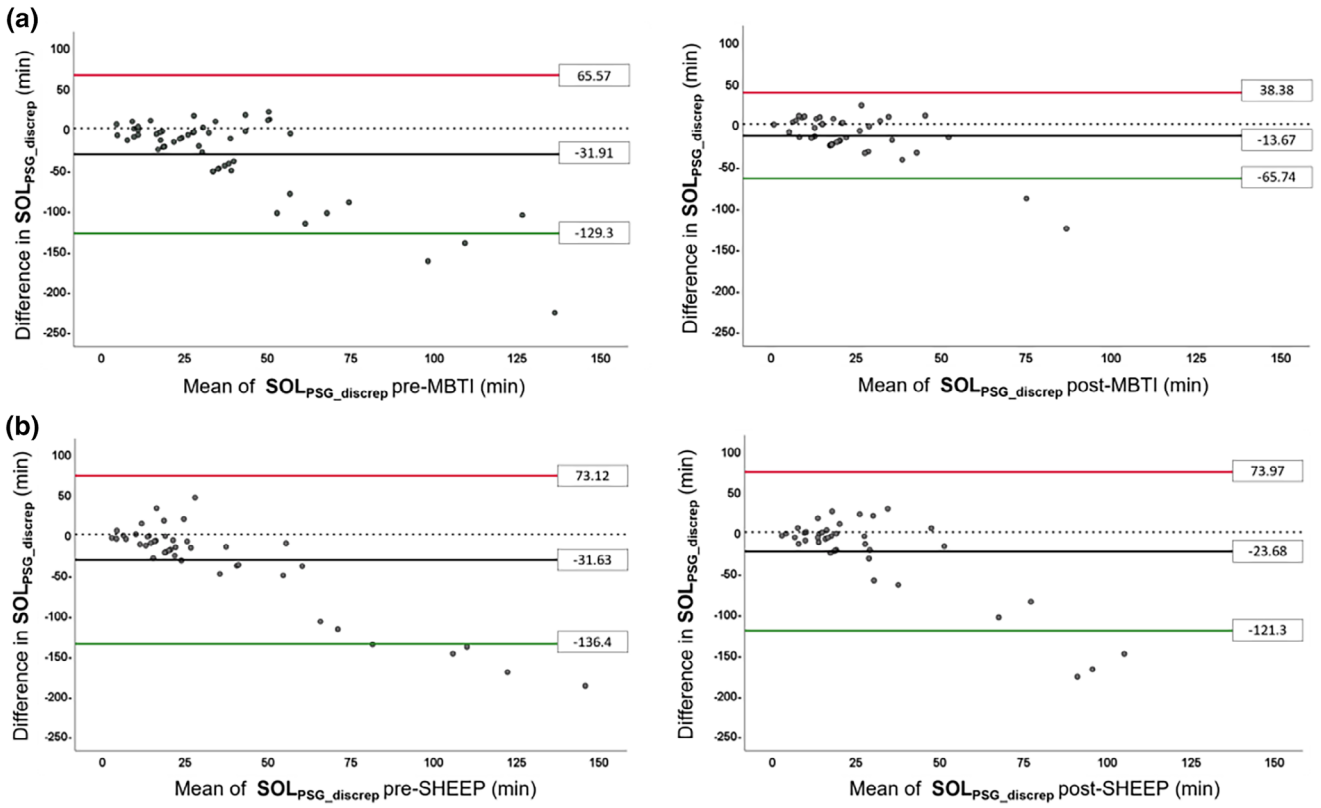

FIGURE 2 Bland–Altman plots presenting the discrepancy and the agreement limits in $SOL_{PSG\_discrep}$ pre- versus post-interventions. (a) MBTI group, (b) SHEEP group. The means of $SOL_{PSG\_discrep}$ are in the black lines. Upper and lower agreement limits (red and green lines) were calculated as the mean difference ± 1.96 standard deviations. Dotted lines denote zero which indicates no difference between the self-reported and objective estimation. The closer the discrepancy average lines are to zero, the more closely the self-reported and objective measures aligned. MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; $SOL_{PSG\_discrep}$, the discrepancy between PSG-recorded and self-reported sleep onset latency

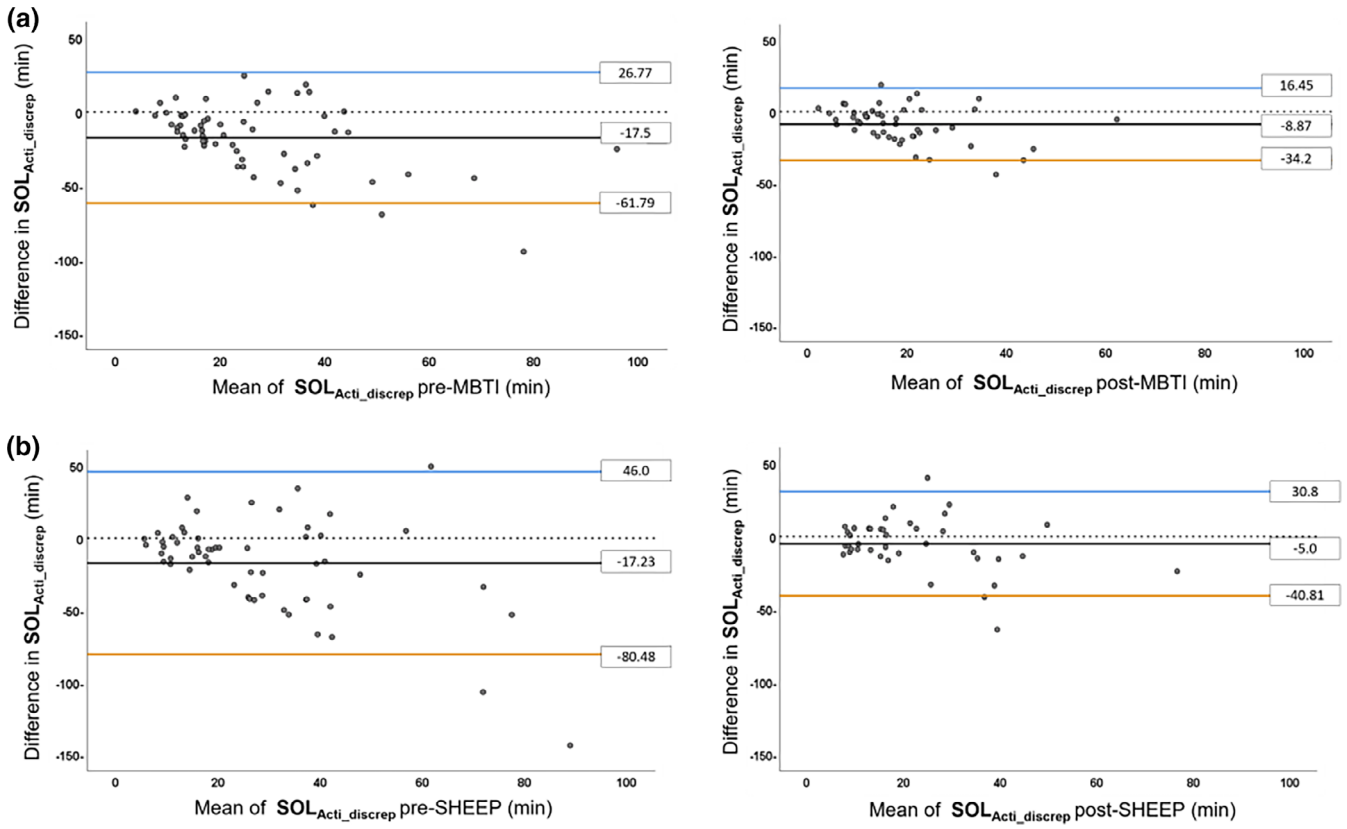

FIGURE 3 Bland–Altman plots presenting the discrepancy and the agreement limits in $SOL_{Acti\_discrep}$ pre- versus post-interventions. (a) MBTI group, (b) SHEEP group. The means of $SOL_{Acti\_discrep}$ are in the black lines. Upper and lower agreement limits (blue and orange lines) were calculated as the mean difference ± 1.96 standard deviations. Dotted lines denote zero which indicates no difference between the self-reported and objective estimation. The closer the discrepancy average lines are to zero, the more closely the self-reported and objective measures aligned. MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; $SOL_{Acti\_discrep}$, the discrepancy between actigraphy-recorded and self-reported sleep onset latency.

TABLE 3 Mean values of ISI, PSQI, FFMQ, and BCT pre- versus post-intervention for both groups

Variable		Mean of pre (SD)	Mean of post (SD)	Mean difference	*t* value	*p* value	Cohen's d
ISI	MBTI	14.98 (3.22)	9.96 (4.22)	5.02	8.499	<0.001	**1.135**
	SHEEP	14.40 (4.26)	11.50 (4.71)	2.90	5.886	<0.001	**0.772**
PSQI	MBTI	11.01 (3.17)	7.56 (3.28)	3.45	7.031	<0.001	**0.939**
	SHEEP	11.09 (3.07)	7.88 (3.46)	3.21	6.866	<0.001	**0.901**
FFMQ	MBTI	129.29 (17.57)	132.80 (17.29)	−3.51	−2.591	0.012	**−0.346**
	SHEEP	130.29 (15.42)	132.01 (14.41)	−1.72	−0.648	0.519	−0.085
BCT	MBTI	0.797 (0.23)	0.888 (0.11)	−0.09	−2.921	0.005	**−0.409**
	SHEEP	0.791 (0.22)	0.831 (0.16)	−0.04	−1.293	0.201	−0.176

Bold values denote statistical significance at the $p < 0.05$, < 0.01, or < 0.001 levels.
ISI, insomnia severity index; PSQI, Pittsburgh sleep quality index; FFMQ, five facets mindfulness questionnaire; BCT, breath counting task; MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme; SD, standard deviation.

interactions ($p = 0.04$) driven by greater decreases in MBTI compared with SHEEP (Table S1).

To compare the changes in sleep discrepancy resulting from each intervention, post-hoc analyses were conducted. We found significant reductions in the discrepancy and the limits of agreements intervals (LOA) for $SOL_{PSG\_discrep}$ post-MBTI intervention with a medium effect size [$d = -0.240$] (Table 2, Figure 2). Additionally, we found that both study groups had significantly decreased $SOL_{Acti\_discrep}$ and LOA following their respective interventions with a medium effect size [MBTI: $d = -0.265$; SHEEP: $d = -0.376$] (Table 2, Figure 3). The changes in

TABLE 4 Correlations between the change in SOL discrepancy versus the change in FFMQ, BCT, ISI, and PSQI from pre- to post-interventions

Variable		$SOL_{PSG\_discrep}$ Pearson's *r*	*p* value	$SOL_{Acti\_discrep}$ Pearson's *r*	*p* value
FFMQ	MBTI	0.084	0.61	−0.038	0.79
	SHEEP	−0.158	0.35	0.122	0.46
BCT	MBTI	0.029	0.87	**−0.396**	0.011
	SHEEP	−0.126	0.46	0.213	0.20
ISI	MBTI	0.182	0.27	**0.362**	0.030
	SHEEP	0.044	0.79	0.119	0.47
PSQI	MBTI	0.161	0.33	0.082	0.84
	SHEEP	0.038	0.82	−0.138	0.40

Bold values denote statistical significance at the $p < 0.05$, < 0.01, or < 0.001 levels. FFMQ, five facets mindfulness questionnaire; BCT, breath counting task; ISI, insomnia severity index; PSQI, Pittsburgh sleep quality index; $SOL_{PSG\_discrep}$, the discrepancy between PSG-recorded and self-reported sleep onset latency; $SOL_{Acti\_discrep}$, the discrepancy between actigraphy-recorded and self-reported sleep onset latency; MBTI, mindfulness-based therapy for insomnia; SHEEP, sleep hygiene, education, and exercise programme.

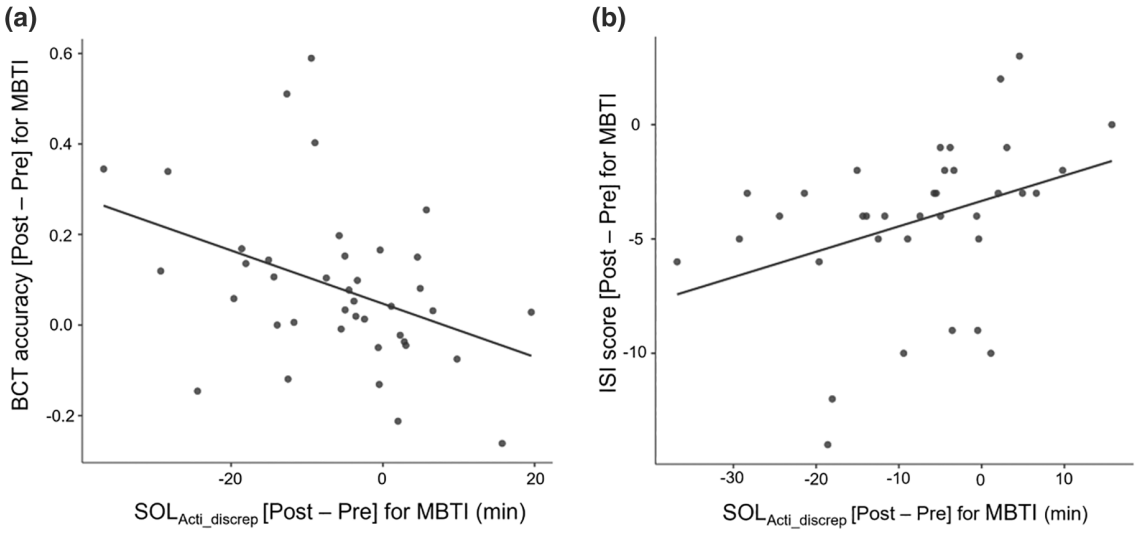

FIGURE 4 Scatter plots for the correlations between the change in SOL discrepancy versus the change in BCT and ISI. (a) A significant negative correlation between the change in SOL discrepancy versus the change in BCT accuracy in the MBTI group. The more reduction in SOL discrepancy was correlated with the more improvement in BCT accuracy (b) A significant positive correlation between the change in SOL discrepancy versus the change in ISI score. The more reduction in SOL discrepancy was correlated with the more reduction in the ISI score. $SOL_{Acti\_discrep}$, the discrepancy between actigraphy-recorded and self-reported sleep onset latency; BCT, breath counting task; ISI, insomnia severity index; MBTI, mindfulness-based therapy for insomnia

$WASO_{PSG\_discrep}$ and $WASO_{Acti\_discrep}$ were not significant for the MBTI group. Unexpectedly, we observed a significant increase in $WASO_{Acti\_discrep}$ in the SHEEP group post-intervention ($d = -0.401$) (Table 2).

Associations between sleep discrepancy and other variables

Our next aim was to test whether the changes in discrepancy were associated with the changes in sleep and mindfulness outcomes. Prior to this, we examined whether these variables were significantly affected by the two interventions. In repeated-measures ANOVA, we found a main effect of time in the ISI score [$F_{(1,112)} = 106.59$, $p < 0.001$] with a significant time × group interactions [$F_{(1,112)} = 7.53$, $p = 0.007$]. Post-hoc analyses showed that the severity of insomnia decreased significantly from moderate to mild in both groups with a large effect size [MBTI: $d = 1.135$; SHEEP: $d = 0.772$] (Table 3).

Additionally, rmANOVA showed a main effect of time on PSQI scores [$F_{(1,112)} = 86.31$, $p < 0.001$] with no significant time × group interactions [$F_{(1,112)} = 0.618$, $p = 0.433$]. Pairwise comparisons showed a significant improvement in the quality of sleep post-interventions in both groups with a large effect size [MBTI: $d = 0.939$; SHEEP: $d = 0.901$] (Table 3).

We next explored how mindfulness was altered by the interventions in our subsample. 2 × 2 ANOVA showed a main effect of time in FFMQ total score as well as BCT accuracy [FFMQ: $F_{(1,112)} = 5.393$, $p = 0.022$; BCT: $F_{(1,103)} = 8.907$, $p = 0.004$] with no significant time × group interactions. In the post hoc analyses, only the MBTI group significantly improved in the subjective and objective measures of trait mindfulness with a medium effect size [FFMQ: $d = -0.346$; BCT: $d = -0.409$] (Table 3).

To explore if different mechanisms may be involved in reducing sleep discrepancy, we correlated trait mindfulness with these variables for the participants in both groups. No correlations were found between the FFMQ and the change in discrepancy in either group. However, we found a significant negative correlation between the change in $SOL_{Acti\_discrep}$ and the change in BCT accuracy only in the MBTI group (Pearson's $r = -0.396$, $p = 0.011$), indicating that less discrepancy in SOL estimation was associated with higher accuracy (Table 4, Figure 4a).

We further correlated the change in the SOL discrepancy with the changes in ISI and PSQI. A significant positive correlation was found only in the MBTI group between the change in $SOL_{Acti\_discrep}$ and the change in ISI score pre- versus post-intervention (Pearson's $r = 0.362$, $p = 0.030$), indicating that less discrepancy in SOL estimation was correlated with lower insomnia symptoms (Table 4, Figure 4b).

4 | DISCUSSION

Although sleep misperception is known to exacerbate insomnia symptoms, studies focussing on understanding and treating this problem are scarce at present. The current paper is the first exploratory analysis to examine whether MBTI, a novel manualised treatment, is efficacious for reducing sleep discrepancies in comparison with an active control group (SHEEP) in a randomised controlled trial.

Over time, we found that MBTI significantly reduced $SOL_{PSG\_discrep}$ and $SOL_{Acti\_discrep}$, whereas SHEEP only reduced $SOL_{Acti\_discrep}$. However, there was no time-by-group interaction in either of these effects. Unexpectedly, $WASO_{Acti\_discrep}$ increased significantly in SHEEP but not in MBTI, resulting in a superior outcome for MBTI participants on this variable. Finally, amongst MBTI but not SHEEP participants, we found that the increases in behaviourally measured trait mindfulness were correlated with reductions in SOL discrepancy, which in turn were correlated with improvements in sleep quality. Our results are broadly consistent with those in prior studies, in which CBTi was found to be effective for reducing SOL discrepancies (Kay et al., 2015). However, we note that our results are preliminary as these predictions were not pre-registered, and we did not correct for multiple comparisons over the tests performed in this analysis. Regardless, given the current pattern of findings, further studies are warranted to test specifically the efficacy of MBTI in reducing sleep discrepancies using a priori hypotheses, to determine whether MBTI is non-inferior to CBT-I (the current gold standard treatment) in improving discrepancy outcomes.

Overall, MBTI was effective in reducing SOL but not WASO discrepancy. Previous studies have suggested that the mechanisms underlying sleep discrepancy during initial sleep onset and night-time awakenings could be different (Perlis et al., 1997). Beta and/or gamma activity (which is associated with cognitive processes) is enhanced at or around sleep onset in patients with insomnia. This kind of activity may hinder the normal ability to initiate sleep onset-related mesograde amnesia. Consequently, the patient with insomnia sustains a level of memory processing that distorts the difference between sleep and wakefulness and impacts retrospective judgements about sleep onset (Perlis et al., 1997). Additionally, many researchers have reported that the reduction in SOL discrepancy could be a possible consequence of cognitive therapies primarily targeting pre-sleep cognitive arousal, ruminative thoughts, and worries related to sleep (Desbordes et al., 2012; Jain et al., 2007). Therefore, by reducing pre-sleep arousal, it is possible that self-reported and objectively measured sleep onset latency had a stronger agreement following treatment.

Given that WASO discrepancy did not change post interventions, this could be due to different underlying mechanisms affecting older adults. Older adults tend to have unique physiological characteristics that might impact how they perceive WASO. This could be as a result of menopause and hormonal changes (Baker et al., 2018), changes in sleep architecture or circadian rhythm (Taillard et al., 2021), or the presence of other sleep disorders (e.g. sleep apnea syndrome) (Suzuki et al., 2017), which can significantly affect how they perceive their sleep. Additional research is needed to determine if beta and/or gamma activity is similarly related to WASO discrepancy in older adults.

Our current results agree with prior literature showing that reduced sleep discrepancy is associated with improvements in sleep quality (PSQI) and insomnia symptoms (ISI) (Dzierzewski et al., 2019; Kay et al., 2015). Although both groups reduced SOL discrepancy, improved sleep quality, and decreased insomnia symptoms, our findings suggest that the underlying mechanism differed between the groups. This assumption was further supported by the presence of significant correlations between the change in sleep discrepancy and the changes in the ISI score and BCT accuracy only in the MBTI group. One possible reason for this is that MBTI focusses on metacognitive processes that have been shown to improve positive mood states and to decrease distractive and ruminative thoughts (Desbordes et al., 2012; Hassirim et al., 2019; Jain et al., 2007; Jankowski & Holas, 2014; Ong et al., 2012). Additionally, a core component of the MBTI programme in our study are behavioural strategies drawn from CBTi, such as sleep consolidation, stimulus control, and sleep hygiene, elements that have previously been linked to reductions in sleep discrepancy after CBTi (Kay et al., 2015; Okajima et al., 2011; van der Zweerde et al., 2019; van Straten et al., 2018). In line with our prediction, targeting behaviours and cognitions related to poor sleep might be essential for resolving sleep discrepancy. A previous study suggested that interventions targeting only poor behaviours towards sleep and lacking the cognitive component might be inadequate to improve other aspects of sleep parameters (Chung et al., 2018).

Interestingly, the relationship between changes in mindfulness and change in sleep discrepancy was seen only for the behavioural measure of mindfulness and not self-report, despite the fact that both these measures improved in the MBTI group. Some researchers have

levelled criticism at relying solely on self-report measures to assess dispositional mindfulness (Grossman, 2011), and the current data highlight a case where the breath counting task but not the FFMQ was a valid predictor of symptom change. This is particularly intriguing as the measurement of sleep discrepancies also involves an objective component (actigraphy or polysomnography), suggesting the breath counting task may be particularly valuable as a correlate of physiological change associated with mindfulness training. In recent years the breath counting task has emerged as one of a handful of behavioural mindfulness measures with adequate psychometric properties (Hadash & Bernstein, 2019). Therefore, future studies are warranted further to explore the links between breath counting task performance and sleep perception, which may in turn guide the development of the breath counting task.

In summary, the present exploratory study aimed to assess the effects of MBTI on subjective-objective sleep discrepancies measured by polysomnography and actigraphy. Our results showed that MBTI and SHEEP were associated with significant reductions in SOL discrepancies, improved sleep quality, and reduced insomnia symptoms, although different intervention components played a different role in each group. The ability to be mindful may be an important ingredient in improving sleep perception in the MBTI group. Although the discrepancy of sleep continuity parameter did not improve significantly in the present study, the treatment outcomes were associated with improvement in most of the questionnaires.

5 | LIMITATIONS

This study has some limitations that need to be acknowledged. As already noted, we did not correct for multiple comparisons across the tests performed in our analysis, nor was the trial specifically designed to assess sleep discrepancy. In this study, we recruited a heterogeneous sample of older adults with sleep disturbances and excluded only those with either cognitive impairments or neurological/psychological disorders. This contrasts with the pilot study of MBTI (Ong et al., 2014), which recruited only patients with primary insomnia and no comorbid disorders. Patients with insomnia tend to report shorter TST/longer SOL/more WASO than controls, compared with older adults who typically report discrepancies in the opposite direction (Edinger & Fins, 1995; Means et al., 2003). These diagnostic-based differences may have confounded the results of the present analysis, and further studies on homogeneous samples are needed to confirm the result.

Moreover, our study did not include a follow-up assessment to determine the long-term effects of both interventions on sleep discrepancy and sleep quality. Therefore, changing individual's perception of time spent in wake after sleep onset or sleep onset latency did not ensure that the underlying cause of sleep disturbances is resolved, or that not perceiving a true sleep problem reduced the long-term side effects of poor sleep.

Future interventional trials should include sleep discrepancy as important outcome measures, and should be designed to target sleep quality and sleep perceptions in older adults with insomnia. An in-depth understanding of the underlying psychophysiological source of sleep discrepancy in patients with insomnia may assist in designing novel treatments targeting the underlying pathophysiology.

AUTHOR CONTRIBUTIONS

Noof Abdullah Saad Shaif and Julian Lim: conceived of the analysis; Noof Abdullah Saad Shaif: carried out the analysis; Julian Lim and Kinjal Doshi: led the data collection; Noof Abdullah Saad Shaif: took the lead in writing the manuscript, all authors provided critical feedback and shaped the manuscript.

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CONFLICT OF INTEREST

The authors report no financial relationships with commercial interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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