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Can music combined with heartbeat sounds help people sleep better?: An exploratory study of middle-aged adults†

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Music often serves as a tool for inducing physiological relaxation, a positive state of mind in individuals who experience sleep difficulties. A recent laboratory study suggested that physiological sounds, including heartbeat (HB) sounds, may induce relaxation. In this study, we explored whether music combined with HBs can improve sleep quality in adults. A total of 70 adults, aged 40 - 68 years, with sleep difficulties, were randomized into a 4-week music+HB intervention, an audiobook control, and a waitlist group, and data from 63 adults were included in the final analysis. Self-report questionnaires were used to assess sleep quality, depression, and anxiety in all the participants. We observed that the symptoms of early morning awakening and subjective sleep quality were significantly improved with the music+HB intervention than in the waitlist group. Specifically, intervention-induced improved sleep quality persisted even for 4 weeks after intervention in individuals without severe depression. We concluded that music combined with HB may be potentially useful as a healthcare self-help tool for individuals with subclinical levels of insomnia or temporary sleep disturbances, as opposed to being a primary treatment modality for patients with clinical-level insomnia and comorbid depressive disorder.

Keywords: sleep, music, heartbeat sounds, mobile application

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Common sleep problems with aging include increased sleep latency, frequent waking, early waking, daytime sleepiness, and fatigue (Lai & Good, 2006). Due to the potential adverse effects (e.g., residual daytime effects and increased tolerance), pharmacological treatments may not sufficiently improve quality of life and cannot be maintained in the long term. Therefore, even if short-term pharmacological approaches are used to treat acute insomnia, these approaches are reported to be more effective when combined with non-pharmacological treatments (e.g., cognitive behavioral therapy [CBT] or relaxation therapy; Schutte-Rodin, Broch, Buysse, Dorsey, & Sateia, 2008).

Previous studies on music therapy for adults with insomnia reported that relaxing music is effective for sleep in the following ways: (1) physiologically (by lowering blood pressure, heart rate, and respiratory rate and reducing sympathetic activity; Good et al., 2001; Lee, Moon, Baek, Lee, & Kim, 2019), (2) emotionally (by helping regulate emotions and improving negative emotions associated with sleep disorders; Saarikallio, 2011), (3) cognitively (by helping to positively distract one from excessive worrying and rumination; Garza-Villarreal et al., 2014). Instrumental music with a slow tempo (50–80 beats per minute, bpm) and lack of syncopation or strong beats using percussion instruments has been reported to induce relaxation responses (Bernardi et al., 2009; Gaston, 1951; Gomez & Danuser, 2007; Trehub & Trainor, 1998). Particularly, music tempo is known to play an important role in inducing mood and physiological responses (Azevedo et al., 2017; Watanabe, Ooishi, & Kashino, 2017). The fact that slow music facilitates relaxation by inducing physiological changes, including reduced sympathetic activity and the regulation of noradrenaline secretion (Chen et al., 2021; Lai & Good, 2006; Shum, Taylor, Thayala, & Chan, 2014), serve as grounds for the use of music therapy for the improvement of sleep. Previous studies (Johnson, 2003; Lai & Good, 2006; Shum et al., 2014) have reported that listening to music for 30–45 minutes every day for 3–4 weeks can significantly improve sleep. However, other studies have shown that music therapy does not have a large effect size as a monotherapy (Harmat, Takács, & Bódizs, 2008; Jespersen & Vuust, 2012; Morin & Benca, 2012), and it produces better results in individuals with less severe insomnia symptoms (Jespersen, Otto, Kringelbach, Van Someren, & Vuust, 2019).

Calming music and white noise are some of the most frequently accessed sounds for improving insomnia symptoms. Compared to other types of white noise, the sound of a heartbeat is highly useful, safe, and universal because it is not typically influenced by context or personal experiences (Devos et al., 2019). In general, slow heart rhythm is associated with low arousal, calmness, and boredom (Gomez & Danuser, 2007). Experimental studies confirmed that the tempo of the sound of a heart beat can alter the listener's actual heart rate and proposed heartbeat sound stimulation as a relaxation technique in a stress situation (Morishima, Sugino, Ueya, Kadotani, & Takadama, 2016; Tajadura-Jiménez, Väljamäe, & Västfjäll, 2008).

A previous study has also shown that the sound of a resting heartbeat can improve sleep quality by shortening sleep latency (Takadama, Tajima, Harada, Ishihara, & Morishima, 2015). A study that compared the effects of different cradle sounds synchronized with individuals' real-time vital signs (heart rate and respiratory cycle) reported that playing the sound at a slightly slower tempo than the actual heart rate and respiratory rate effectively shortened sleep latency (Morishima et al., 2016). Taken together, these laboratory studies have presented theoretical evidence supporting the relaxing and deep sleep-inducing effects of vital sounds (e.g., heartbeat and breathing sounds), however, no experimental study has investigated the effects of these vital sounds on sleep in individuals with sleep problems. Therefore, we developed a mobile app for playing and using sleep-inducing music with heartbeat sounds and conducted a randomized controlled trial (RCT) investigating the effects and utility of this app in middle-aged adults with subjective sleep-related problems.

Method

Participants and procedure

Figure 1 is a diagram showing the flow of participants through the study. Eighty-two adults with subjective sleep problems were initially recruited via online bulletin boards. Individuals who had been diagnosed with a sleep or other mental disorder who were taking prescribed medications or undergoing other nonpharmacological treatments were excluded. Further, and individuals with an Insomnia Severity Index (ISI) score greater than or equal to the cutoff for severe insomnia were excluded. Finally, data from 63 adults (aged 40–68 years; 74.6% female) were included in the analysis after excluding participants who dropped out. The present study protocol was reviewed and approved by the institutional review board of Seoul National University Hospital (IRB No. H-2006-151-1135). Informed consent was submitted by all subjects when they were enrolled. The consent form stated that participants could discontinue participation at any time without penalty if they felt psychologically or physically uncomfortable or no longer wanted to participate in the study.

We used a three-group repeated measures RCT design. There were 22 participants in the music combined with heartbeat sounds group (Music+HB group), 19 participants in the comparison group (audiobook group), and 22 participants in the waitlist group. All three groups were included in the comparison between the pre- and post-training assessments. After 4 weeks, we administered a follow-up evaluation of both Music+HB and audiobook groups. Seventeen participants in the music+HB group and 17 participants in the audiobook group were included in the analysis of changes among pre-training, post-training, and follow-up.

Music combined with heartbeat sounds. A list of music is presented in the Appendix 1. Night-time music included slow (32–80 bpm) classical and pop instrumental music arranged to feature simple structure and melody. The order of the playlist was determined in consideration of the tempo (fast to slow) and overall pitch (high to low). Daytime music included relatively fast-tempo (56–96 bpm), less repetitive, and more rhythmic classical and new-age music. Heartbeat sounds were mixed into the music at a sound level that was detectable but did not hinder listening to the original music. The music+HB group was able to play the entire playlist in order or choose specific music to listen to on the mobile app.

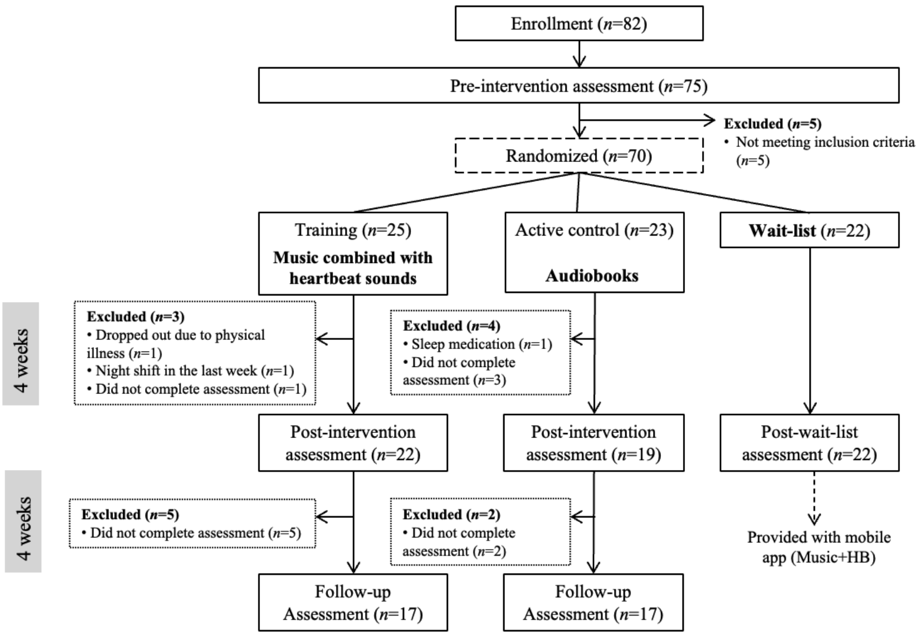

Figure 1. Diagram outlining the flow of participants through the study

Further, the participants were provided a mini Bluetooth speaker to connect to a smartphone and a soft cushion within which the speaker could be inserted. For a total of four weeks, participants were free to use the app wherever and whenever they wanted (the recommended frequency was approximately 45 minutes, at least five times a week, including at night).

Audiobook group. To control for placebo effects, the comparison group was assigned to listen to an audiobook for the same length of time (4 weeks) that the Music+HB group listened to music. The active control group also used the same tools as the music-HB group. Reading or listening to a book is a common strategy used to improve sleep, thus, the audiobook group was considered to be an ecologically valid comparison group (Jespersen et al., 2019) for music+HB group. The participants were provided with five novel audiobooks that were not emotionally intense via the mobile app we developed (see Appendix 1).

Waitlist control group. The participants randomized to the waitlist group did not receive any interventions and only completed the assessments. After the final assessment, the waitlist group was also provided with the music app.

Measurements

Insomnia Severity Index (ISI). The ISI is comprised of seven questions regarding severity of insomnia, sleep satisfaction, daytime dysfunction caused by sleep problems, and worries about sleep throughout the previous two weeks. The original version of the scale classifies a total score of 8–14 as sub-threshold insomnia, 15–21 as moderate insomnia, and 22–28 as severe insomnia (Bastien, Vallières, & Morin, 2001). In a validation study of the Korean version, a total score of 15 or higher was set as the cutoff for clinical insomnia (Cho, Song, & Morin, 2014).

Pittsburgh Sleep Quality Index (PSQI). Because the participants did not have clinical insomnia, in addition to objective sleep scores, subjective sleep quality was also included in the sleep indices. Even in nonclinical samples, self-perceived sleep quality has been reported to be highly correlated with an individual's quality of life (Marques, Meia-Via, da Silva, & Gomes, 2017) and depression (Grandner, Kripke, Yoon, & Youngstedt, 2006; Huang, Peck, Mallya, Lupien, & Fiocco, 2016). The PSQI is considered the gold standard for assessing subjective sleep quality in both clinical and nonclinical populations (Fabbri et al., 2021) and may be well indicative of negative views and dissatisfaction with sleep (Grandner et al, 2006).

The PSQI is comprised of 18 items across the following seven domains: sleep latency, subjective sleep quality, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping medication, and daytime dysfunction. Each of the seven domains is rated on a scale from 0–3 for a total score of 0–21. A score of 5 or greater indicates the presence of sleep problems (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; Sohn, Kim, Lee, & Cho, 2012).

Center for Epidemiologic studies depression scale (CES-D). The CES-D is a 20-item questionnaire based on the frequency of depressive symptoms the respondent has experienced during the previous week (Chon, Choi, & Yang, 2001). In a Korean study, a score of 15 or less classified as normal, a score of 16 to 22 as mild depression, and a score of 23 or more as severe depression (Cho & Kim, 1993).

State-Trait Anxiety Inventory (STAI). For the present study, we used only 20 items of the state anxiety subscale. A score of less than 54 indicated normal levels, while a score of 54–58 indicated mild levels, a score of 59–63 indicated moderate levels, and a score of 64 or greater indicated severe levels of anxiety (Hahn, Lee, & Chon, 1996; Spielberger, 1983).

Revised Anxiety Sensitivity Index (ASI-R). The ASI-R is comprised of 36 items that measure threatening beliefs regarding arousal (e.g., fear of respiratory symptoms, fear of cognitive dyscontrol, etc; Kim et al., 2004; Taylor & Cox, 1998).

Smartwatch. All participants were asked to wear a smartwatch (Xiaomi Mi Band 3) before going to bed for a week before commencing the training, as well as during the four weeks of training in order to measure mean sleep duration. Since previous studies have shown that wearable-based sleep duration shows a significant but weak correlation with self-reported sleep duration (Maynard, Appleman, Cronin-Golomb, & Neargarder, 2021; Teo et al., 2019), this study sleep duration scores obtained by two different methods were used in the analysis.

Statistical analyses

Baseline demographic factors and assessment scores were compared among the groups using a multivariate analysis of variance (MANOVA) for continuous variables and a chi-square test for categorical variables. In addition, the differences in the assessment scores between participants who completed the full training program and those who were withdrawn before completing training were analyzed using Mann-Whitney U-test.

Sleep and emotional domain scores of pre- and post-intervention were compared for the three groups using a 3 × 2 repeated measures MANCOVA. Daily sleep duration (for one week prior to training) that significantly differed among the groups at the baseline and depression score, which was not significantly different among the groups but could influence training outcomes, were controlled for as covariates. A post-hoc comparison was performed for variables with significant group (music+HB vs. audiobook vs. waitlist) × time (pre- and post-intervention assessment) interactions. Since we had a small sample size per group, we calculated the F statistic and partial η^2 to determine the effect size for intergroup comparisons to establish the actual significance of the significance probability. A partial η^2 of .06 or higher is considered a medium effect size, while a partial η^2 of .14 or higher is considered a large effect size (Cohen, 1988).

Next, the music+HB and audiobook groups were additionally analyzed using a 2´3 repeated measures MANCOVA with their follow-up data included. The sleep scores at baseline, after training, and at follow-up between the two groups were compared using two paired *t*-tests. (Note: Power calculation using G*Power 3.1 [Faul, Erdfelder, Lang, & Buchner, 2007] revealed 16 participants per group as the minimal sample size for a repeated measures MANOVA to achieve a power of 80% and a level of significance of 5%. However, excluding clinically depressed participants, the sample was not large enough to test the assumptions required for a repeated measures MANOVA.) All statistical analyses were performed using the SPSS 18.0.

Results

Table 1 presents participants' demographic characteristics and pre-intervention assessment scores. Daily sleep duration measured using a smartwatch for one week prior to training significantly differed among the groups. The CES-D score did not significantly differ among the groups, but the mean score in the music+HB and waitlist groups was 17, above the cut-off (16 points) of probable depression (Cho, Nam, & Suh, 1998), while that in the audiobook group was 14, below the threshold. There were no significant differences in the demographic factors and baseline scores between individuals who completed the training and individuals who were withdrawn (n=7; $n_{music+HB}$=3, $n_{audiobook}$=4).

Sleep qualities, depression, and anxiety

Pre-post intervention assessment scores between groups are presented in Table 2. After controlling for baseline daily sleep duration and

CES-D score as covariates, the score for ISI item 1c (early morning awakening, EMA) had a group×time interaction effect (partial η^2=.188, p<.05), and the post-hoc test confirmed that the mean difference between the music+HB and waitlist group was significant (F=2.582, p=.040). The scores for PSQI item 5a (difficulty with sleep initiation; partial η^2=.122, p<.05) and item 6 (subjective sleep quality; partial η^2=.186, p<.05) also had group×time interaction effects. Regarding subjective sleep quality (PSQI item 6), the change of mean score (from post- to pre-training) was greater in the music+HB and audiobook groups than the waitlist group (post-hoc F=4.711, p=.013). On the other hand, the total PSQI, sleep latency (PSQI item 2), sleep duration (PSQI item 4 & smartwatch), depression, and anxiety scores did not show significant group×time interaction.

Music + HB vs. audiobook group: pre, post, and follow-up assessments

Sleep scale scores were compared between the music+HB and audiobook groups using pre-, post-intervention, and follow-up (4 weeks after the end of intervention) assessment scores. The results are presented in Table 3. In this analysis, data from 34 participants ($n_{music+HB}$=17; $n_{audiobook}$=17) who completed all three rounds of

Table 1. Demographic characteristics and pre-intervention assessment scores

		Music+HB (n=22)	Audiobook (n=19)	Wait-list (n=22)	F / $\chi 2$	p
Demographic characteristics	Age	50.23 (7.48)	47.79 (6.92)	51.55 (8.90)	1.186	.312
	Gender (male/female)	6/16	5/14	5/17	0.132	.936
	Duration of sleep disturbances (years)	4.67 (7.76)	2.92 (2.87)	4.96 (3.67)	0.848	.434
	Medical treatment for physical diseases (yes : no)	5:17	6:13	4:18	1.031	.597
Sleep	ISI	14.45 (4.34)	13.37 (4.47)	13.45 (3.90)	0.434	.650
	PSQI	9.73 (2.37)	9.53 (3.88)	10.68 (2.88)	0.858	.429
	Daily sleep duration (minutes)†	399.94 (78.51)	448.24 (36.47)	409.84 (44.62)	4.817	**.011**
Depression and anxiety	CES-D	17.91 (9.89)	14.79 (6.70)	17.68 (7.31)	0.907	.409
	STAI-S	42.18 (9.22)	41.11 (9.28)	45.09 (7.10)	1.216	.304
	ASI-R	25.91 (22.03)	23.58 (21.16)	29.50 (23.21)	0.373	.690

Notes. Scores are displayed as means and standard deviations.
† Measured using a smartwatch.
Music+HB=Music combined with heartbeat sounds; ISI=Insomnia Severity Index; PSQI=Pittsburgh Sleep Quality Index; CES-D=Center for epidemiologic studies depression scale; STAI-S=State-Trait Anxiety Inventory-State anxiety subscale; ASI-R=Anxiety Sensitivity Index-Revised

assessments were included, and baseline daily sleep duration, depression scores, and training compliance reported immediately after training and at follow-up were controlled for as covariates. Compliance did not significantly differ between the two groups but did vary widely across individuals, with the music+HB group showing a relatively higher level of compliance; hence, this variable was entered as a covariate. (The subjective satisfaction and compliance scores of the music+HB and audiobook groups are presented in Appendix 2.) The results showed that the reduction of sleep problems shown immediately after training was maintained until the follow-up assessment in both groups, but the group×time interaction was not significant.

Table 2. Comparisons between the groups on pre-post intervention assessment

	Music+HB[1] (n=22)		Audiobook[2] (n=19)		Wait-list[3] (n=22)		F (time)	F (group)	F (T×G)	post hoc (LSD)
	pre M (SD)	post M (SD)	pre M (SD)	post M (SD)	pre M (SD)	post M (SD)				
ISI total	14.45 (4.34)	10.27 (4.06)	13.37 (4.47)	8.21 (4.52)	13.45 (3.90)	11.82 (4.84)	2.504	0.527	5.834**	
ISI #1c (Early morning awakening)	1.86 (1.04)	1.00 (0.76)	1.74 (0.81)	1.00 (0.75)	1.59 (0.85)	1.55 (1.10)	3.571	0.286	6.705**	1>3
PSQI total	9.73 (2.37)	8.64 (3.00)	9.53 (3.88)	7.37 (3.53)	10.68 (2.88)	8.73 (2.73)	0.020	0.583	1.111	
PSQI #5a (Difficulty with sleep initiation)	2.18 (0.85)	1.50 (1.22)	1.95 (0.85)	1.37 (1.12)	2.05 (0.90)	2.00 (1.07)	0.040	0.379	4.035*	
PSQI #6 (Subjective sleep quality)	1.95 (0.38)	1.41 (0.59)	1.74 (0.56)	1.32 (0.48)	1.78 (0.49)	1.82 (0.59)	0.465	1.557	6.627**	1,2>3
Daily sleep duration (min)	399.94 (78.51)	396.95 (69.56)	448.24 (36.47)	430.97 (70.96)	409.84 (44.62)	366.54 (103.44)	1.366	3.684*	1.716	
CES-D	17.91 (9.89)	16.59 (9.80)	14.79 (6.70)	14.68 (11.34)	17.68 (7.31)	17.00 (10.06)	0.268	0.443	0.262	
STAI-S	42.18 (9.22)	41.73 (11.18)	41.11 (9.28)	39.68 (10.86)	45.09 (7.10)	43.05 (10.85)	0.229	0.745	0.207	

Notes. MANCOVA, with covariates of pre-intervention daily sleep duration and CES-D score, was used to assess whether the groups differed on ISI and PSQI. Music+HB=Music combined with heartbeat sounds; ISI=Insomnia Severity Index; PSQI=Pittsburgh Sleep Quality Index; CES-D=Center for epidemiologic studies depression scale; STAI-S=State-Trait Anxiety Inventory-State anxiety subscale; ASI-R=Anxiety Sensitivity Index-Revised

*p<.05, **p<.01

Effects of music + HB in participants without depression

Severe depressive symptoms have been previously reported to diminish the effectiveness of digital therapy (Manber et al., 2008), so changes in sleep scores in the music+HB (n=12) and audiobook (n=15) groups were examined after excluding five participants in the music+HB group and two participants in the audiobook group who scored above the clinical cutoff for depression at baseline (CES-D≥25). The results showed that there were significant changes in nearly all variables at the post-training assessment in comparison to that at baseline. On the other hand, the total ISI score and score for subjective sleep quality (PSQI item 6) significantly changed between the

Table 3. Comparisons between the groups (Music+HB vs. Audiobook) on pre-post-F/U assessment

	Music+HB (n=17)			Audiobook (n=17)			F (time)	F (group)	F (T×G)
	Pre M (SD)	Post M (SD)	F/U M (SD)	Pre M (SD)	Post M (SD)	F/U M (SD)			
ISI total	14.29 (4.37)	9.59 (3.71)	8.18 (4.45)	13.00 (4.51)	8.12 (4.78)	7.47 (5.15)	0.539	1.242	0.521
PSQI total	9.41 (2.15)	8.18 (3.03)	8.06 (3.19)	9.47 (4.05)	7.53 (3.64)	7.29 (3.93)	0.686	0.924	0.214

Notes. MANCOVA, with covariates of pre-intervention daily sleep duration, CES-D score, and training frequency, was used to assess whether the groups differed on ISI and PSQI. Music+HB=Music combined with heartbeat sounds; ISI=Insomnia Severity Index; PSQI=Pittsburgh Sleep Quality Index

Table 4. Score changes except for clinically depressed (CES-D≥25) subjects in Music+HB (n=12) and Audiobook (n=15)

		Pre M (SD)	Post M (SD)	F/U M (SD)	t (pre-post)	t (post-f/u)
ISI total	Music+HB	13.17 (3.69)	9.97 (4.05)	7.08 (4.25)	3.626**	2.574*
	Audiobook	12.33 (4.32)	7.27 (4.42)	6.47 (4.53)	7.035***	1.492
ISI #1c (Early morning awakening)	Music+HB	1.92 (0.90)	1.08 (0.67)	0.75 (0.75)	3.079*	1.773
	Audiobook	1.60 (0.83)	0.87 (0.74)	0.87 (0.74)	4.036**	0.000
PSQI total	Music+HB	9.25 (2.45)	8.08 (3.45)	7.25 (3.44)	1.465	1.890
	Audiobook	8.73 (3.20)	6.53 (2.36)	6.27 (2.60)	3.973**	0.441
PSQI #5a (Difficulty with sleep initiation)	Music+HB	1.83 (0.83)	1.17 (1.19)	1.17 (1.19)	2.602*	0.000
	Audiobook	1.80 (0.77)	1.20 (1.01)	1.00 (0.93)	3.154**	1.146
PSQI #6 (Subjective sleep quality)	Music+HB	1.92 (0.29)	1.50 (0.52)	1.17 (0.39)	2.803*	2.345*
	Audiobook	1.60 (0.51)	1.20 (0.41)	1.07 (0.59)	3.055**	1.000

Notes. Music+HB=Music combined with heartbeat sounds; ISI=Insomnia Severity Index; PSQI=Pittsburgh Sleep Quality Index
*p<.05, **p<.01, ***p<.001

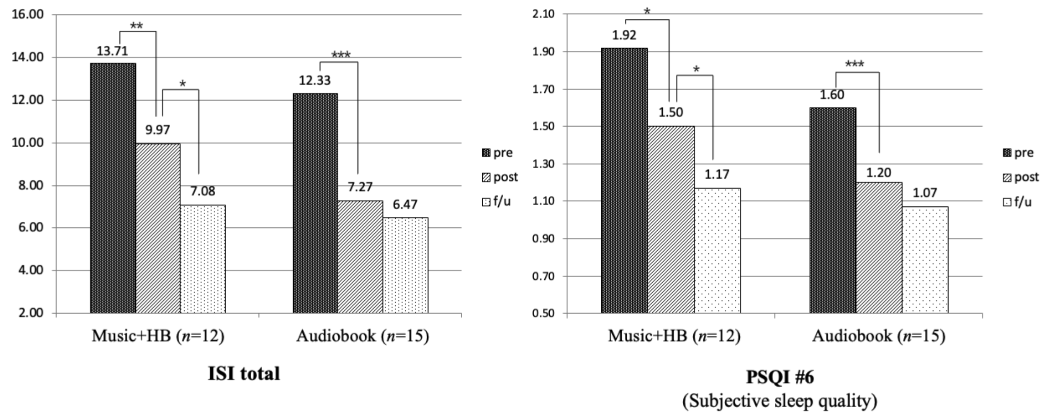

Figure 2. Score changes except for clinically depressed subjects: ISI total and PSQI #6 scores (*$p<.05$, **$p<.01$, ***$p<.001$)

post-training assessment and follow-up only in the music+HB group. These results are presented in Table 4 and Figure 2.

Discussion

After four weeks of intervention, the music+HB, audiobook, and waitlist groups showed lower total ISI and PSQI scores, without statistically significant differences among the groups. However, the improvements in EMA and subjective sleep quality were significantly greater in the music+HB group than that in the waitlist group. Depression and anxiety scores did change in all groups, but the changes were not significantly different among the groups.

In this study, the following things must be considered when interpreting changes in scores between baseline and post-training in the three groups. First, the participants were randomly assigned to one of the three groups based on their baseline ISI score and age and after excluding withdrawals, the audiobook group had about 50 minutes longer daily sleep duration than the music+HB group at the baseline. In addition, the audiobook group reported the shortest durations of insomnia and lowest levels of emotional difficulties. Although we have attempted to control for these differences by entering daily sleep duration and depression score as covariates, the baseline differences may still have influenced the overall effects of the intervention (Jespersen, Koenig, Jennum, & Vuust, 2013). Second, because most of the participants were middle-aged women, it is possible that difficulties with sleep initiation or EMA were more common than problems with sleep duration or daytime dysfunction (Brown, Gallicchio, Flaws, & Tracy, 2009). For these reasons, we observed significant intergroup differences in the changes of the scores only for specific sleep problems in the ISI and PSQI between pre- and post-intervention assessment.

Mediating role of depression

Regarding the baseline depression scores of our participants, 30 participants had a CES-D score of above the cutoff for probable depression (16 points; $n_{music+HB}$=10; $n_{audiobook}$=7, $n_{waitlist}$=13), and 11 of them ($n_{music+HB}$=5, $n_{audiobook}$=3, $n_{waitlist}$=4) had a score of above the cutoff (25 points) for definite depression (Park & Kim, 2011), indicating that 17.4% of the participants had clinical depression. Thus, we compared the sleep problem scores between the music+HB and audiobook groups after excluding those with severe symptoms of depression (CES-D≥25) that may contribute to sleep problems, compliance, and other outcomes. The results showed more distinct improvements of sleep in both groups after training, while the total ISI score and subjective sleep quality score significantly changed at follow-up compared to the post-training assessment only in the music+HB group.

Insomnia and depression are highly comorbid diseases, and a substantial percentage of patients with major depressive disorder (MDD) meet the diagnostic criteria for chronic insomnia (around 67% as reported by Franzen & Buysse, 2008). Depression severity is a mediator of the effects of treatment on insomnia (Ashworth et al., 2015), and pharmacological treatment for depression is known to enhance the effects of CBT-I in patients with sleep disorder and depression (Manber et al., 2008). In addition to sleep problems, a study examining the effects of digital treatment in other general healthcare areas (e.g., obesity management) reported that participants with severe baseline depression have difficulty continuing to comply with digital treatment on their own and cannot reap the benefits of treatment because they do not develop positive expectations for the treatment outcomes or motivation to continue undergoing treatment (Kim et al., 2020). Further research should investigate the effect size of treatments that combine music+HB interventions with non-pharmacological treatments that have already proven effective (e.g., CBT, relaxation, etc.).

This study has the following limitations. First, because single item scores from the ISI and PSQI were used to measure EMA, difficulty with sleep initiation, and subjective sleep quality, there is a possibility that there may be limitations in terms of criterion validity.

Second, although we recruited individuals who had not been diagnosed with or received treatment for a sleep disorder, a considerable number of the recruited participants had a baseline insomnia (ISI) score exceeding the cutoff for subclinical insomnia (23 out of 63 participants, 36.5%). The average illness duration for sleep problems was also long, at approximately four years. In other words, we can infer that some of our participants had insomnia that would require active medical treatment. Previous studies have documented that a low-intensity intervention such as music listening is not adequately effective as a monotherapy, so these interventions have been recommended as an adjuvant therapy for subclinical insomnia symptoms coupled with another treatments (Jespersen et al., 2019). Furthermore, some of our participants had CES-D scores of 25 or higher (n=11) indicating clinical depression or ASI-R scores of beyond 50.47 (n=11), the average score among patients with panic disorder. Based on reports that 40–69% of patients with MDD develop insomnia symptoms before other symptoms (Johnson, Roth, & Breslau, 2006), deteriorating sleep quality is sometimes viewed as a precursor of depression (Ashworth et al., 2015). Thus, it is possible that our study sample contained people who are likely to be diagnosed with MDD, as opposed to insomnia, in the future. Further, the fact that our sample was predominantly women in their 40s and 50s seems to be relevant to this issue, so our results cannot be generalized to populations without. sleep or other mental disorders.

Third, reactions to music and heartbeat sounds widely vary across individuals, so it is possible that the music content we provided (e.g., tempo and pitch) did not serve as a meaningful stimulation for all participants uniformly. To address this issue, individual neuroleptic thresholds or levels of arousal should be monitored to provide individualized music content featuring heartbeat sounds at the optimal tempo.

Fourth, we validated the effectiveness of music combined with heartbeat sounds but could not examine the relaxing and sleep-inducing effects of heartbeat sounds alone due to the methodology. In our study, there were no significant differences in the training effects between the two groups, and it is possible that both groups showed improvements in sleep regardless of the type of content (e.g., music combined with heartbeat sounds or audiobook alone) because the act of listening to an audio stimulus replaced habits that hindered sleep, such as rumination and hypervigilance (Dickson & Schubert, 2020; Tang et al., 2021; Trahan, Durrant, Müllensiefen, & Williamson, 2018).

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심장박동 소리가 결합된 숙면 유도 음악 앱의 수면개선 효과: 중장년기 성인 대상 탐색적 연구

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본 연구에서는 신체적, 심리적 이완을 유도한다고 알려진 안정 상태의 심장박동 소리가 결합된 음악 및 이를 재생하는 모바일 앱을 개발하고, 이것이 중장년기 일반인의 수면 개선에 효과가 있는지 검증하였다. 수면과 관련된 불편감을 호소하는 40-68세 일반인 70명이 연구에 참여하여 실험집단, 비교집단(오디오북), 대기집단으로 무선배정되었으며, 4주동안 실험집단은 심장박동 소리가 결합된 음악을, 비교집단은 오디오북을 듣도록 하였다. 효과평가를 위해 훈련 전, 후, 추후(훈련종료 4주 후) 총 3차례 자기보고식 설문을 통해 수면문제 심각도, 정서적 어려움(우울, 불안)을 평가하였고, 최종 63명의 자료를 분석에 활용하였다. 연구 결과, 모든 집단에서 수면문제 총점과 정서적 어려움 점수가 다소 감소하였으나 집단 간 유의한 차이는 없었다. 하지만 하위 수면장해 지표 중 새벽에 너무 일찍 잠에서 깨는 문제 및 주관적 수면의 질은, 실험집단의 증상 개선 정도가 대기집단에 비해 유의하게 큰 것으로 나타났다. 특히 실험집단 내에서 심한 우울증상이 없는 참여자들은 훈련을 통한 수면의 질 호전이 훈련 종료 4주 이후에도 지속되었다. 이러한 결과를 바탕으로 심장박동 소리가 결합된 음악 앱은 일상생활에서 수면 관련 불편감을 경험하는 일반인, 즉 임상적 수준의 불면증과 우울증의 공존병리가 없는 개인을 위한 헬스케어 보조 도구로서 잠재적 활용성이 있음을 논의하였다.

주요어: 수면, 음악, 심장박동 소리, 모바일 앱

Appendix

Appendix 1. List of music combined with heartbeat sounds

No.	Composer	Title	Tempo (bpm)	Instrument	Duration
Night-time					
1	Shubert	Ave Maria D.839 Op.52 No.6	40	guitar	5:18
2	Chopin	Prelude No.21 In B Flat Major, Op.28	68	piano	2:42
3	Carpenters	Solitaire	69	various	4:21
4	Carpenters	Rainy Days and Mondays	65.5	various	3:30
5	Bach	Cantata BWV 208	80	guitar	6:06
6	Mendelssohn	Songs Without Words No.1 In E Flat Major Op.30	64	piano	4:18
7	Mendelssohn	Songs Without Words No.3 In E Major Op.30	62	piano	1:43
8	Carpenters	Only Yesterday	60	various	3:49
9	Carpenters	A Song for You	58.5	various	4:09
10	Bach	Cantata BWV 156	64	guitar	2:21
11	Bach	Cantata BWV 1	60	guitar	1:26
12	Chopin	Nocturnes No.2 In E Flat Major Op.9 - Andante	64	guitar	8:15
13	Bach	Orchestra Suite No.3 In D Major, BWV 1068	54	piano	3:39
14	Carpenters	Close to you	47.5	various	2:55
15	Bach	Cantata BWV 147	40	guitar	5:20
16	Schumann	Kinderszenen Op.15 No.1 - Of Foreign Lands and Peoples	32	guitar	2:47
17	Bach	Cantata BWV 22	40	guitar	7:01
Daytime					
1	Mendelssohn	Lieder Ohne Worte Book V. No.6 In A Major, Op.62	63	piano	3:03
2	Steve Barakatt	Rainbow Bridge	61.5	various	3:33
3	Steve Barakatt	Day By Day	81	various	3:22
4	Steve Barakatt	California Vibes	96	various	3:59
5	Vivaldi	The Four Seasons Concerto No.4 In F Minor Op.8 RV.297 Winter II. Largo	80	guitar	1:46
6	Mozart	Piano sonata No.13 in B-flat major K333 II	56	orgol	8:46

Notes. We used royalty-free music available on SoundCloud.

The audiobook intervention included a choice among the following audiobooks:
'The Stars' (Alphonse Daudet), 'A Day in the Life of Kubo the Novelist' (Taewon Park), 'What Men Live By' (Lev Nikolayevich Tolstoy), 'The Darling' (Anton P. Chekhov), 'The Lighthouse Keeper of Aspinwall' (Henryk Sienkiewicz).

Appendix 2. Scores of subjective satisfaction and compliance ratings

	Music+HB (n=22)	Audiobook (n=19)	t	p
1. Sense of relaxation	2.86 (1.04)	2.63 (0.90)	0.769	.447
2. Overall sleep-inducing effect	2.64 (1.18)	2.26 (1.15)	1.026	.311
3. Diversion in daytime	2.18 (1.01)	1.68 (0.95)	1.631	.111
4. Compliance (frequency of use) : Intervention period	4.59 (1.59)	4.05 (1.75)	1.024	.312
: Between post-f/u assessment	1.76 (1.92)	1.82 (2.21)	-0.083	.935

Notes. Scores are displayed as means and standard deviations.
The following three items were included in the assessment of training satisfaction: After listening to the training content (music combined with heartbeat sounds or audiobook), 1) has your body and mind relaxed? 2) were you able to sleep better or did you feel sleepy when listening to it at night before bed? 3) has it helped you overcome daytime drowsiness and lethargy? Next, compliance with training, that is, the frequency of using the app, was determined based on a self-report rating of weekly average training frequency and duration using a seven-point Likert scale (0-6).
Response criteria: item #1~3 (0) Not at all, (1) not so much, (2) somewhat, (3) quite helpful, (4) very helpful;
#4 (0) Not used at all, (1) 1 or 2 times a week, less than 20 minutes per session, (2) 1 or 2 times a week for 30-40 minutes per session, (3) 3-4 times a week, less than 20 minutes per session, (4) 3-4 times a week for 30-40 minutes per session, (5) more than 5 times a week, less than 20 minutes per session, (6) more than 5 times a week for 30-40 minutes per session