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Original Report

Effects of Somatosensory Games on Heart Rate Variability and Sleep-Related Biomarkers in Menopausal Women With Poor Sleep Quality

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Abstract

Background and Objectives: The aim of this study was to investigate the effects of 12-week somatosensory games on heart rate variability and sleep-related biomarkers in middle-aged women with poor sleep quality.

Research Design and Methods: Twenty-nine women with poor sleep quality were recruited as participants randomly assigned into ring fit adventure exergame group (RFA, $n = 15$) and control group (CON, $n = 14$). The RFA group received ring fit adventure exergame for 60 min each time, 2 times a week, for 12 weeks. The CON group was not allowed to participate in intervention activities during the study period. Heart rate variability, sleep quality, cortisol, serotonin, and high-sensitive C-reactive protein were measured before and after the 12-week intervention.

Results: The Pittsburgh Sleep Quality Index total score in the RFA group was significantly lower compared with the CON group. The value of the standard deviation of normal NN intervals and the root mean square of the successive RR Differences were significantly increased in the RFA group, when compared with the CON group. The change in the logarithm of high frequency (log HF) was significantly higher and change in the logarithm of low frequency to high frequency ratio (log LF/HF) was significantly lower in the RFA group, when compared to the CON group. The change level of serotonin in the RFA group was significantly higher compared with the CON group.

Discussion and Implications: The results suggest that somatosensory games might improve sleep quality, increase serotonin level, and decrease sympathetic nerve activities in middle-aged women with poor sleep quality.

Keywords: Aerobic exercise, Autonomic nervous system, Exergame, Sleep hormone

Menopause represents one of the most pivotal phases in a woman's life. Complications associated with menopause, such as sleep disorders, can significantly affect a woman's physical health and contribute to a decline in mental well-being (Smith et al., 2018; Valiensi et al., 2019). As the body undergoes functional declines, disruptions in sleep patterns often occur, resulting in frequent awakenings, prolonged sleep onset latency, and fragmented sleep patterns. These disturbances interfere with the body's cellular and hormonal regulation, leading to a cascade of inflammatory reactions over time. This chronic inflammatory burden not only compromises brain function and circulatory health but also increases susceptibility to chronic cardiovascular and metabolic diseases (Grandner et al., 2013; Valiensi et al., 2019).

Previous research has documented the close relationship between the autonomic nervous system and sleep quality. Sympathetic activity is for "fight and flight," while the parasympathetic activity helps you "rest and digest" (de Zambotti et al., 2018). Sleep disorders often disrupt the autonomic nervous system balance, which leads to sympathetic hyperexcitability and vagal hypoactivity. This inappropriately increased sympathetic activity can result in cardiovascular diseases, such as hypertension, nondipping blood pressure, and heart failure (Miglis, 2016). Previous study showed that insomnia patients who sleep under 6 hr face shorter sleep durations, longer times to fall asleep, more awakenings, and poorer sleep efficiency, along with higher average heart rate and blood pressure (Jarrin et al., 2018). Heart rate variability (HRV) provides information about functioning of the autonomic nervous system and interaction of sympathetic and parasympathetic activity (Stein & Pu, 2012). One study reported that sleep disturbances may lead to increases in the low frequency/

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high frequency ratio (LF/HF) and decreases in HF, the root mean square of the successive RR Differences (rMSSD) and total power (TP; Ucak et al., 2024).

In 2020, the World Health Organization (WHO) updated its physical activity guidelines, recommending that middle-aged and older adults engage in a minimum of 150–300 min of moderate-intensity aerobic physical activity per week. Alternatively, they can opt for at least 75–150 min of moderate-to-high-intensity aerobic physical activity, or an equivalent combination of both intensity levels, over the course of the week (Bull et al., 2020). Additionally, incorporating moderate- or high-intensity strength training in 2 or more days per week is advised. This regimen has been shown to enhance cardiopulmonary function, increase muscle mass, bolster bone health, promote cognitive function and sleep, mitigate the risk of cardiovascular disease and type 2 diabetes, and reduce the occurrence of depression and all-cause mortality (Bull et al., 2020). One study reported that engaging in aerobic exercise or a combination of aerobic and resistance training over a period of 10 weeks could reduce sleep fragmentation and body mass index, and significantly enhance sleep quality and efficiency (Bonardi et al., 2016). Another study demonstrated that moderate-intensity aerobic training could increase serotonin and melatonin levels, leading to improvements in sleep quality (Al-Sharman et al., 2019). Numerous studies have reported significant improvements in sleep quality as a result of engaging in physical activities (Jurado-Fasoli et al., 2020; Yang et al., 2012). Consequently, developing strategies to enhance their willingness to participate in physical activity has become important. Past study suggested that using interactive somatosensory exergames as intervention was able to promote physical activity among older adults, and improve cardiorespiratory endurance, cognitive performance, lower extremity stability, and balance (Garcia et al., 2016; Gomes et al., 2018; Rodrigues et al., 2018). However, it is unclear whether somatosensory games can improve sleep quality and sleep-related biomarkers in middle-aged women with poor sleep quality. Therefore, the purpose of this study was to investigate the effect of 12 weeks of somatosensory games on HRV and sleep-related biomarkers in middle-aged women with poor sleep quality.

Method

Study Design and Participants

Participants of the current study were recruited from communities in several districts of Taipei, Taiwan. Potential subjects were recruited through recruitment flyers, social media platforms, and by word of mouth. Interested participants were screened by using a semistructured telephone interview. We recruited sedentary middle-aged menopausal women and older community-dwelling adults (aged ≥45 years) with poor sleep quality (PSQI >5) to participate in this study. The participants were excluded if they had any of the following conditions: non-menopausal women, nonpoor sleep quality, Mini-Mental State Examination <24, International Physical Activity Questionnaire (IPAQ) more than 600 MET (metabolic equivalent of task)-min/week, untreated hypertension, other cardiovascular disease, problems that are contraindicated to exercise, inability to provide informed consent or cooperate. Randomization took place after informed consent forms had been received. The standard process of random assignment was performed through Microsoft Excel's random number generation function. First, each participant was given a number, which was then generated to a random number via the "RAND()" function in Excel. Second, these random numbers were sorted through ascending order. Last, the participants were divided into two groups from the median of random numbers to ensure that the number of participants in each group was approximately equal. This randomization process was carried out by an independent researcher unaffiliated with the collection of data and the assessment of results in order to ensure the objectivity and fairness of the allocation. All experimental procedures regarding assessment and RFA training programs were carefully explained to the participants before they were asked to sign and return the written informed consent that had been approved by the Ethics committee of National Taiwan University in Taiwan (NTU-REC NO: 202203EM034).

Exergames Course Programs

Nintendo Switch RingFit Adventure was used to execute a somatosensory game program. Exergames were performed for 60 min per session, two sessions a week for 12 weeks. Each session consisted of 5 min of warm-up, 35 min of aerobic training, 15 min of strength training, and 5 min of cool-down. The heart rate reserve (HRR) was used to determine exercise intensity zones based on the American College of Sports Medicine (ACSM) standards. The formula for calculating the percentage of HRR is as follows:

[206.9 – (0.67 × age) – resting heart rate (RHR)] × percentage + RHR = desired intensity.

In the current study, exercise intensity was adjusted in real time according to the participants' heart rate to ensure the safety and effective training. Participants' heart rate was continuously tracked by using a heart rate monitoring device (Zephyr Technology Corporation, Annapolis, MD, USA). The heart rate tracking setting was determined by categorizing heart rates into three zones according to the preestimation of the maximum heart rate: low (HRR 20%–39%), medium (HRR 40%–59%), and high (HRR 60%–84%). Depending on the phase of training, the coaches would adjust the exercise intensity according to the heart rate data. Every 4 weeks, the heart rate threshold would be adjusted according to participants' adaptation. Personalized exercise program was used to ensure that each participant could achieve the best training effect within the safe range.

In the training programs, participants followed a virtual coach in running and fitness exercise games, and received feedback via Joy-Con controllers. Each exercise game was selected based on its intensity and the participants' acceptability. We also developed 10 fitness exercises focusing on cardiorespiratory fitness, limb function, and core muscle strength, including aerobic exercises, presses, shoulder presses, front presses, bow pulls, overhead arm twists, and triceps kickbacks, squats, adductor training, and yoga poses from the RFA-provided list. Each training session was supervised by 2–3 fitness coaches (Figure 1).

Sleep Quality

Sleep quality was measured by the Chinese version of the Pittsburgh Sleep Quality Index (CPSQI) aiming to identify subjective poor sleep quality and sleep disorder. The CPSQI comprises seven component scores, which are summed to create a global score ranging from 0 to 21. The components include time to bed, time of sleep onset, waking time after

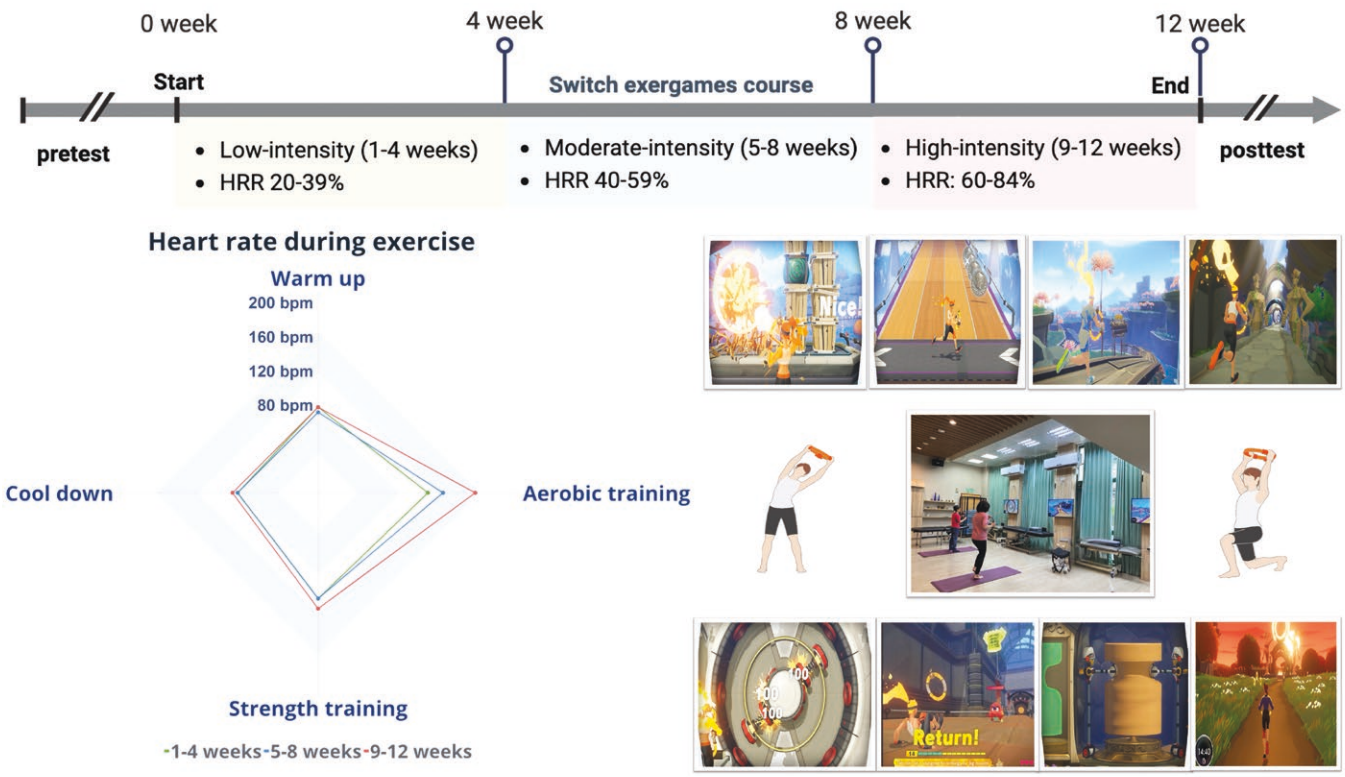

Figure 1. The experimental procedure and timeframe of the study. HRR = heart rate reserve; bpm = beat per minute.

sleep onset, time of getting up, total sleep time, and sleep quality, with higher scores indicating poorer sleep quality. A global CPSQI score ≥ 5 is evidence of poor sleep quality, and this cutoff score has demonstrated a high sensitivity (98%) and moderate specificity (55%) in identifying poor sleep quality.

Heart Rate Variability Measurement

Resting heart rate and HRV parameters were assessed in a relaxed supine position by using a Polar heart rate monitor (POLAR, RS800CX, Kempele, Finland). The HRV data were further analyzed by Kubios HRV software (version 4.0, Biosignal Analysis and Medical Imaging Group, Department of Physics, University of Kuopio, Kuopio, Finland). The participants rested in supine position for at least 15 min before continuous recording was started with using a Polar heart rate monitor and simultaneous recording of breathing patterns for 10 min. The assessment was conducted for all participants between 9 a.m. and 11 a.m. in consideration of diurnal fluctuations, and took place in a temperature-controlled room maintained at 22–24 °C. The following time domains were analyzed: inter-beat (RR) intervals, standard deviation of normal-to-normal (NN) intervals (SDNN) and square root of the mean of the sum of the squares of differences between successive NN intervals (rMSSD). The following frequency domains were analyzed: low-frequency (LF) power (0.04–0.15 Hz), high-frequency (HF) power (0.15–0.4 Hz), TP, and the ratio of LF-to-HF power (LF/HF).

Blood Sample Collection and Biochemical Analysis

Fasting venous whole blood samples (10 mL) were collected in tubes with heparin (BD Vacutainer, USA) at 9 a.m. to 11 a.m., and then centrifuged at 4 °C, 3,000 rpm for 10 min to obtain serum samples. The serum samples were then stored at −80 °C until biochemical analysis. The items of blood biochemistry included high-sensitivity C-reative protein (HsCRP), cortisol, and serotonin. Serum HsCRP levels were quantified by IMMAGE 800 system (Beckman Coulter, Brea, USA). Serum serotonin concentrations were determined by using an enzyme-linked immunosorbent assay (ELISA) from a commercial serotonin kit (Enzo Life Sciences, ADI-900-175). Serum cortisol levels were evaluated by using a cortisol ELISA kit (Cayman Chemical Co., Ann Arbor, MI, USA).

Statistical Analyses

All values were reported as mean ± *SD*. All data sets were analyzed and plotted by SPSS software version 25 (IBM Corp., Armonk, NY, USA) and GraphPad Prism 8.0 (GraphPad Software, La Jolla, CA, USA). Shapiro–Wilk test was used to assess data normality. A mixed-design two-way analysis of variance (group × time) was performed to examine differences in all variables after 12 weeks of intervention. The statistical significance was set at $p < .05$.

Results

Flow of Participants

A total of 40 women were examined for their eligibility; 10 were excluded. Thirty middle-aged women with poor sleep quality were randomly assigned to one of two groups: the control group (CON, $n = 15$) and the ring fit adventure exergame group (RFA, $n = 15$). There were no adverse effects or complications after intervention in any of the two groups during the study period. Finally, 29 participants completed the study with 14 participants in CON group and 15 participants in

RFA group. One participant's data was excluded from analysis due to technical problem. A flow diagram of the study is presented in Figure 2.

Baseline Characteristics of the Participants

All participants were assigned into the CON and RFA groups, with baseline results presented in Table 1. There were no significant differences at baseline between groups in the distribution of age (57.50 ± 9.00 vs 56.46 ± 6.09, $p = .279$), height (155.49 ± 5.29 vs 157.24 ± 5.25, $p = .386$), body weight (BW, 59.78 ± 16.71 vs 54.43 ± 8.53, $p = .367$), body mass index (23.86 ± 3.67 vs 21.93 ± 2.91, $p = .146$), waist-hip ratio (WHR, 0.88 ± 0.03 vs 0.85 ± 0.05, $p = .105$), total physical activity (Total PA, 494.26 ± 95.62 vs 509.47 ± 88.27, 0.644), or years since menopause (10.33 ± 4.00 vs 8.42 ± 4.61, $p = .277$).

Effects of Exergame on Subjective Sleep Quality

The sleep quality assessed by the PSQI questionnaire is shown in Supplementary Table 1. A statistically significant interaction effect was shown in PSQI Global Score, Sleep quality, Sleep duration, Sleep efficiency, and Sleep disturbance. Therefore, the results suggested that intervention time and exergame conditions did significantly affect the subjective sleep quality. Analysis of the simple main effect revealed a significant difference between the CON and RFA groups across time. There were significant differences between pre- and postintervention in the RFA group. Several values significantly decreased after exergame, including the PSQI Global Score (8.20 ± 2.85 to 5.13 ± 2.50, +Δ = −3.07 ± 3.81, $p < .05$; Supplementary Table 1 and Figure 1A), Sleep quality (1.73 ± 0.59 to 1.00 ± 0.66, +Δ = −0.73 ± 0.88, $p < .05$), Sleep duration (1.47 ± 0.64 to 1.07 ± 0.46, +Δ = −0.40 ± 0.63, $p < .05$), Sleep

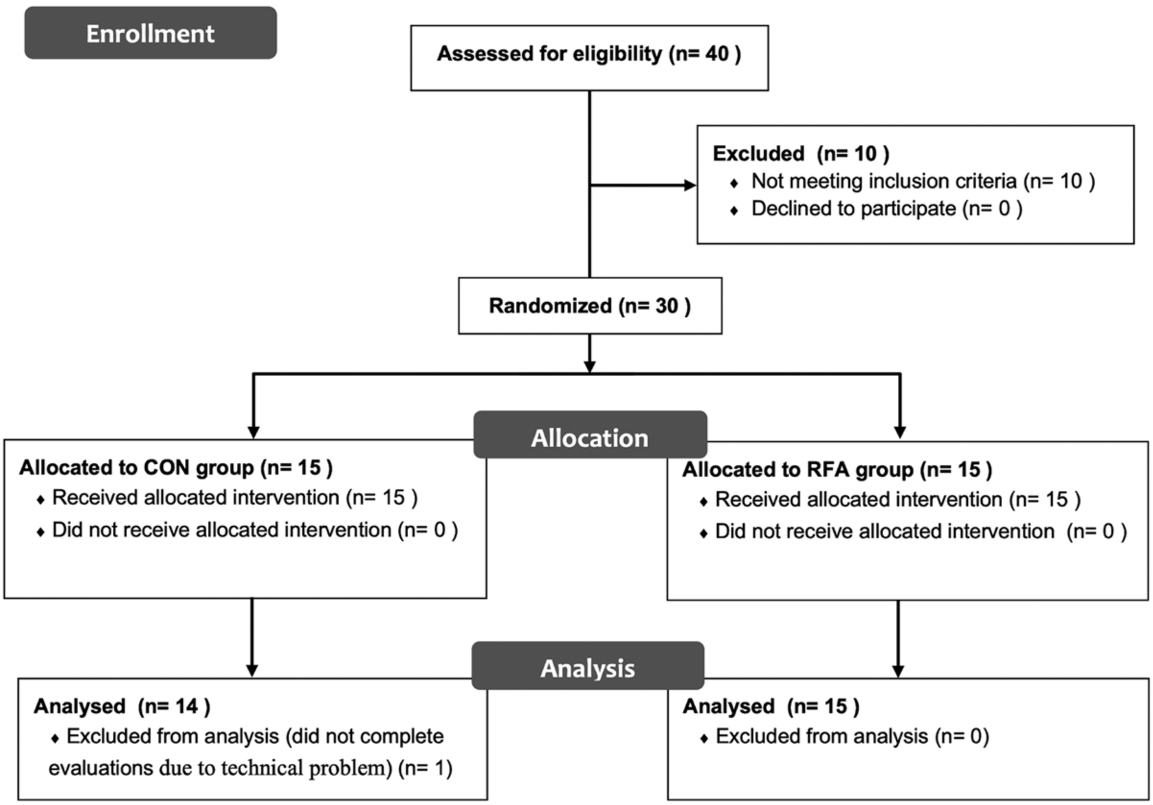

Figure 2. Participants Flow Diagram. CON = control group; RFA = ring fit adventure exergame group.

Table 1. Baseline Characteristics of Participants in the Control and Ring Fit Adventure Exergame Groups

Variables	CON group (n = 14) Mean ± SD	RFA group (n = 15) Mean ± SD	p Value
Age (years)	59.00 ± 6.01	56.46 ± 6.09	.279
Height (cm)	155.49 ± 5.29	157.24 ± 5.25	.386
Body weight (kg)	57.50 ± 9.00	54.43 ± 8.53	.367
BMI (kg/m^2)	23.86 ± 3.67	21.93 ± 2.91	.146
Waist-hip ratio	0.88 ± 0.03	0.85 ± 0.05	.105
Total PA (MET-min/week)	494.26 ± 95.62	509.47 ± 88.27	.644
Years since menopause (years)	10.33 ± 4.00	8.42 ± 4.61	.277

Note: BMI = body mass index; CON = control; MET = metabolic equivalent of task; PA = physical activity; RFA = ring fit adventure. Independent t tests were used for statistical analyses.

efficiency (1.47 ± 0.74 to 0.67 ± 0.62, +Δ = −0.80 ± 1.08, $p < .05$), and Sleep disturbance (1.46 ± 0.64 to 0.86 ± 0.64, +Δ = −0.60 ± 0.63, $p < .05$; Supplementary Table 1). There was no significant interaction effect in the Sleep latency and Daytime dysfunction (Supplementary Table 1).

Effects of Exergame on Heart Rate Variability

SDNN and rMSSD showed a group × time interaction between the CON and RFA groups (Table 2). Analysis of the simple main effect revealed a significant difference between the CON and RFA groups across time (Table 2). Figure 3D and E presents the changes in SDNN and rMSSD levels examined in this study. The changes in SDNN (CON group vs RFA group: Δ −4.64 ± 9.73 vs Δ7.69 ± 12.1, $p < .05$) and rMSSD (CON group vs RFA group: Δ −3.69 ± 12.64 vs Δ12.97 ± 20.10, $p < .05$) in the RFA group were significantly higher compared with the CON group. There was no significant interaction effect in the HR and R-R interval (Table 2 and Figure 3B).

The log HF and logLF/HF showed a group × time interaction between the CON and RFA groups (Table 2). Analysis of the simple main effect revealed a significant difference between the CON and RFA groups across time (Table 2). Figure 3F–H presents the changes in logLF, logHF, and logLF/HF levels examined in this study. The changes in log HF (CON group vs RFA group: Δ −0.071 ± 0.097 vs Δ −0.002 ± 0.061, $p < .05$) in the RFA group were significantly higher compared with the CON group (Figure 3G). The changes in logLF/HF (CON group vs RFA group: Δ0.091 ± 0.127 vs Δ0.002 ± 0.087, $p < .05$) in the RFA group were significantly lower compared with the CON group (Figure 3H). There was no significant interaction effect in the logTP and logLF (Table 2 and Figure 3C and F).

Effects of Exergame on Sleep-Related Biomarkers

Serotonin showed a group × time interaction between the CON and RFA groups (Table 3). Analysis of the simple main effect revealed a significant difference between the CON and RFA groups across time (Table 3). Figure 4C presents the changes in HsCRP, cortisol, and serotonin levels examined in this study. The changes in serotonin (CON group vs RFA group: Δ −12.36 ± 65.14 vs Δ38.33 ± 48.72, $p < .05$) in the RFA group were significantly higher compared with the CON group (Figure 4A). There was no significant interaction effect in the HsCRP and cortisol (Table 3 and Figure 4B and C).

Discussion

Our major findings can be summarized as follows: (1) the somatosensory exergames enhanced sleep quantity. (2) The somatosensory exergames exhibited higher rmSSD and SDNN, and log HF. (3) The CON exhibited higher log LF/HF. (4) The serotonin level was increased after somatosensory exergames. We therefore suggest that a well-designed 12-week somatosensory exergames could be one of the exercise regimens for improving sleep quantity, autonomic nervous system activities, and sleep hormone production in menopausal women with poor sleep quality.

According to the ACSM exercise prescription guidelines, individuals with regular exercise habits tend to experience significantly better sleep quality compared to those without such habits (Vanderlinden et al., 2020). In a study by Reid et al., 23 healthy older adults, aged 55 years and older and active community members, with sedentary lifestyles and sleep disorders, underwent 16 weeks of progressive aerobic exercise training. The intensity ranged from 55% to 75% of their maximum heart rate, with each session lasting from 10 to 15 min to 30 to 40 min. The study revealed that the exercise program effectively enhanced subjective sleep quality, reduced depression, alleviated hypersomnia, and addressed issues with concentration (Reid et al., 2010). Another study found that a 10-week exercise regimen involving a combination of resistance exercise with aerobic or aerobic exercise effectively reduced BMI and sleep fragmentation in obese women, while significantly improving sleep quality and efficiency (Bonardi et al., 2016). The results of this current study, which implemented a 12-week progressive somatosensory exercise program designed using somatosensory exergames, aligned with those of previous research. This intervention similarly reduced sleep fragmentation and enhanced both sleep quality and efficiency.

Table 2. Comparison of Heart Rate Variability Between Control and Ring Fit Adventure Exergame Groups

Heart rate variability	CON group (n = 14)		RFA group (n = 15)		Group × time	"Time"	"Group"
	Pre Mean ± *SD*	Post Mean ± *SD*	Pre Mean ± *SD*	Post Mean ± *SD*			
Time domain							
Heart rate (beat)	67.37 ± 7.71	69.05 ± 9.09	66.12 ± 13.18	63.06 ± 5.94	0.283	0.190	0.126
R-R interval (ms^2)	891.04 ± 121.71	887.36 ± 135.55	929.16 ± 134.88	962.93 ± 98.99	0.267	0.394	0.348
SDNN (ms^2)	25.72 ± 18.38	22.37 ± 16.34	24.81 ± 16.98	32.50 ± 17.89	0.006*	0.015*	0.510
rMSSD (ms^2)	27.36 ± 21.22	24.90 ± 22.38	24.31 ± 16.80	37.29 ± 27.91	0.013*	0.053	0.613
Frequency domain							
log TP (nu)	1.68 ± 0.05	1.67 ± 0.01	1.67 ± 0.03	1.67 ± 0.03	0.910	0.798	0.631
log LF (nu)	1.64 ± 0.12	1.74 ± 0.04	1.71 ± 0.09	1.71 ± 0.12	0.052	0.017*	0.603
log HF (nu)	1.72 ± 0.08	1.65 ± 0.04	1.67 ± 0.07	1.66 ± 0.06	0.030*	0.007*	0.452
log LF/HF	0.95 ± 0.11	1.05 ± 0.05	1.02 ± 0.09	1.02 ± 0.09	0.035*	0.009*	0.515

Notes: CON = control; HF = high-frequency power in normalized units; LF = low-frequency power in normalized units; LF/HF = the ratio of LF-to-HF power; log = log-transformed values; Pre = pretest; Post = posttest; R-R = inter-beat; rMSSD = root mean square of the successive RR Differences; RFA = ring fit adventure; SDNN = standard deviation of all NN intervals.
*$p < .05$.

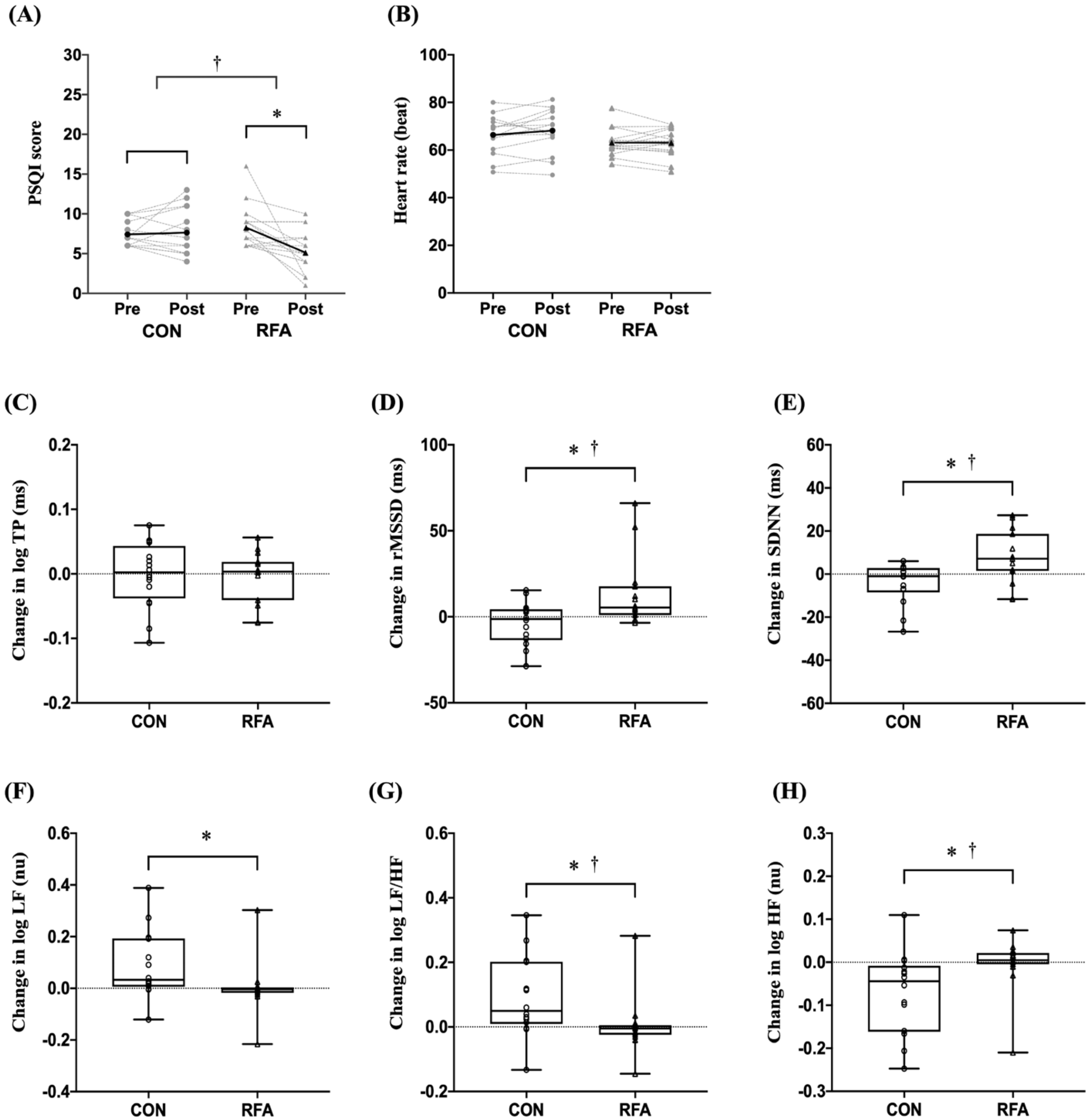

Figure 3. Effects of the somatosensory games on the sleep quality and heart rate variability. (A) Pittsburgh Sleep Quality Index score; (B) heart rate; (C) change in SDNN; (D) change in RMSSD; (E) change in TP; (F) change in logLF; (G) change in logHF; and (H) change in logLF/HF. CON = control group; HF = high frequency; LF = light frequency; RFA = ring fit adventure exergame group; RMSSD = root mean square of the successive RR Differences; SDNN = standard deviation of all NN intervals. Values represent mean ± *SD*. † denotes the significant "Treatment (Group) × Time" interaction. $p < .05$. * denotes the significant differences between the CON and RFA groups.

Numerous physiological and pathological processes, including sleep disorders and emotional or physiological stress, can lead to an overloading of the sympathetic nervous system, consequently increasing the risk of cardiovascular or metabolic diseases (Jarrin et al., 2018; Miglis, 2016). Several studies have demonstrated that exercise or physical activity of moderate or high intensity can enhance the balance between sympathetic and parasympathetic nervous system activities within the autonomic nervous system (Sloan et al., 2009; Tseng et al., 2020). Varas-Diaz et al. conducted a study involving 6 weeks of exergaming-based dance training and observed a significant increase in the HF component of HRV, along with a notable decrease in the LF/HF ratio (Varas-Diaz et al., 2021). In our study, we found that the control group experienced a greater change in the logLF/HF ratio compared to the experimental group. The logLF/HF ratio reflects the balance between sympathetic and parasympathetic nervous system activity levels, suggesting that postmenopausal women

Table 3. Comparison of Cardiovascular Health Index Between Control and Ring Fit Adventure Exergame Groups

Variables	CON group (*n* = 14)		RFA group (*n* = 15)		Group × time	"Time"	"Group"
	Pre	Post	Pre	Post			
	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*	Mean ± *SD*			
hsCRP (mg/dL)	0.10 ± 0.08	0.25 ± 0.48	0.08 ± 0.08	0.09 ± 0.09	0.291	0.111	0.604
Cortisol (µg/dL)	5.56 ± 2.67	7.16 ± 1.94	6.99 ± 3.69	8.82 ± 5.95	0.911	0.481	0.271
Serotonin (µg/dL)	214.71 ± 103.26	207.00 ± 75.92	211.99 ± 137.61	250.32 ± 127.77	0.024*	0.074	0.752

Notes: hsCRP = high-sensitivity C-reactive protein; Pre = pretest; Post = posttest.
*$p < .05$.

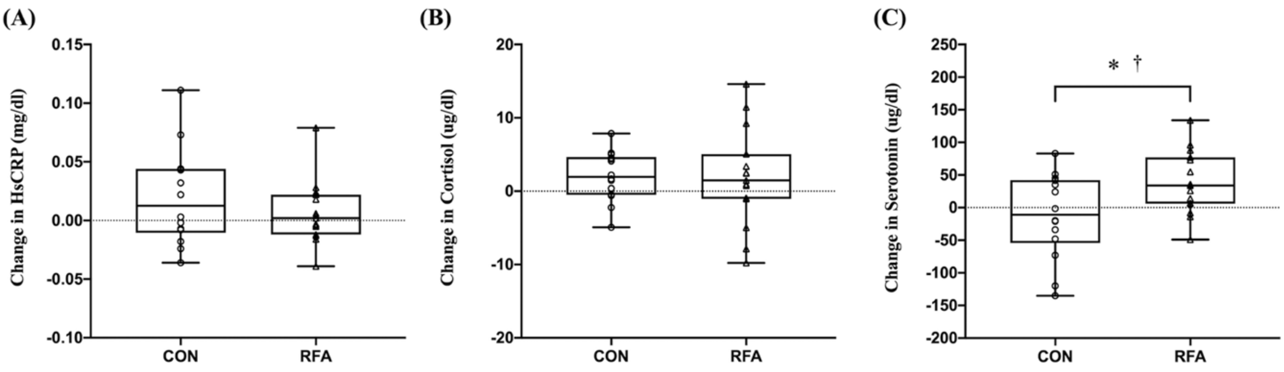

Figure 4. Effects of the somatosensory games on the sleep-related biomarkers. (A) HsCRP; (B) cortisol; and (C) serotonin. CON = control group; HsCRP = high-sensitive C-reactive protein; RFA = ring fit adventure exergame group. Values represent mean ± *SD*. * denotes the significant differences between the CON and RFA groups. † denotes the significant "Treatment (Group) × Time" interaction. $p < .05$.

with poor sleep quality may have heightened sympathetic nerve activity, potentially leading to long-term autonomic nervous system dysregulation. Through a 12-week progressive somatosensory exergame intervention, our study not only showed improvements in sleep quality but also the balance indicators of sympathetic and parasympathetic nervous system activity levels, thereby mitigating excessive sympathetic nerve activation.

Sleep regulation involves a complex interplay of various hormones and neurotransmitters. With advancing age, hormonal changes become intricately linked with physiological functions and sleep patterns. Of particular importance is the relationship between melatonin secretion and serotonin concentration (Lee et al., 2021). As individuals age, circulating levels of serotonin and melatonin tend to decline, potentially contributing to sleep disturbances among older adults due to decreased synthesis and secretion of these neurotransmitters and hormones (Erland & Saxena, 2017; Grad & Rozencwaig, 1993). Additionally, menopausal women experience a significant decline in estrogen and progesterone levels, which can affect serotonin synthesis and release. Previous research indicated that estrogen can enhance serotonin synthesis and receptor activity. Consequently, hormonal fluctuations can lead to increased mood swings, sleep disturbances, and depressive symptoms (Bethea et al., 2002). Serotonin, the end product of L-tryptophan metabolism, serves as a crucial neurotransmitter that regulates mood, depression, and sleep cycles. Its involvement in Rapid Eye Movement sleep is well documented, and decreased serotonin levels have been linked to insomnia (Hartmann, 1974; Wyatt et al., 1970). Serotonin release in the diencephalon and cerebrum likely plays a key role by modulating neural pathways, thereby contributing to the improvement of sleep quality. Exercise has consistently been shown to have a significant stimulatory effect on the serotonin pathway, leading to increased serotonin levels. Elevated levels of norepinephrine and serotonin in the synaptic cleft following exercise contribute to improved mood, alleviation of depression, and regulation of sleep cycles. One study showed that engaging in moderate-intensity aerobic training three times a week for 1 hr per session over 6 weeks can raise serotonin and melatonin levels in the bloodstream (Al-Sharman et al., 2019). Serotonin is the precursor to melatonin, meaning changes in serotonin levels will directly affect melatonin production (Lee et al., 2021). Serotonin also plays a key role in regulating mood and stress responses. Therefore, by analyzing serotonin levels, one can observe changes in sleep or stress status earlier and more comprehensively, rather than relying solely on changes in melatonin levels (Monti, 2011). In our study, participants who underwent the 12-week progressive somatosensory exergame regimen exhibited heightened serum serotonin concentrations. This indicated that the 12-week progressive somatosensory exergame intervention has the potential to enhance sleep quality by increasing serotonin levels, a crucial neurotransmitter in the brain.

Cardiovascular-related diseases primarily affect adults or older individuals. However, if this demographic continues to maintain a sedentary lifestyle, their cardiovascular health will suffer negative consequences. As technology advances, games are no longer exclusively enjoyed by the younger generation. Emerging interactive somatosensory exergames have gained considerable support in the literature for their effectiveness in motivating older adults to engage in physical activity. These games provide valuable clinical and sports science interventions that promote physical activity among older adults, improve balance (Afridi et al., 2018; Gomes et al., 2018; Morone et al., 2016; Sato et al., 2015), enhance self-confidence (Rosenberg et al., 2010), increase functional abilities (Maillot et al., 2014; Rica et al., 2020), walking speed (Agmon et al., 2011; Garcia et al., 2016; Rodrigues et al., 2018) and muscle strength (Jorgensen, 2014). In clinical settings, patients have increasingly been opting for interactive somatosensory exergames, such as those available on the Nintendo Wii, as a preferred mode of rehabilitation. Patients show greater motivation and engagement in such activities. Notably, a study involving elderly individuals aged 63–94 demonstrated that up to 86% of participants completed a 12-week Wii exergame intervention (Rosenberg et al., 2010). A similar study employing an 8-week intervention using switch exergames, with sessions lasting 40 min once a week, reported a 33% reduction in lower back pain following the intervention (Sato et al., 2021). This study employed switch exergames as an intervention over a 12-week period and observed significant enhancements in sleep quality among participants. This finding suggested that such interventions can serve as effective exercise training methods, making it a viable recommendation for postmenopausal women. This study utilized a somatosensory ring fit adventure exergame as an exercise intervention to develop a progressive aerobic exercise regimen which is according to ACSM's exercise prescription guidelines. Individualized exercise HRR zones were determined based on participants' ages, with continuous monitoring of exercise intensity and status using heart rate and ratings of perceived exertion throughout the program. Each participant successfully achieved the target heart rate for each stage of the program, indicating the feasibility and effectiveness of employing somatosensory exergames to design exercise programs tailored for the elderly population.

The present study had some limitations. Although we standardized the measurement times for all participants between 9 a.m. and 11 a.m. to minimize heterogeneity, there are inherent limitations with HRV measurement techniques. There is significant variability among HRV methods. Our study's small sample size might limit the applicability of our results. Our findings might not be extrapolated to other populations since we only included sedentary postmenopausal middle-aged women (i.e., aged ≥45 years). Lastly, our study recruited participants based on the subjective PSQI scale, so we could not determine their actual physiological sleep conditions. Future studies might consider using objective measurement methods. Further studies are required to evaluate these points. Despite these limitations, we believe our study on healthy community-dwelling adults should be a valuable reference.

The present study concluded that a 12-week progressive somatosensory exergame intervention could be an effective exercise regimen for enhancing parasympathetic activity and serotonin levels, thus improving sleep quality in postmenopausal women with sleep disorders. Therefore, this exercise option holds promise as a viable option for increasing physical activity among postmenopausal women.

Supplementary Material

Supplementary data are available at *Innovation in Aging* online.

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Conflict of Interest

The authors declare no conflict of interest.

Data Availability

Data reported in this article are available on request. The study was not preregistered.

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Author Contributions

Y.-Y. Lin and H. Ting contributed to the conceptualization; Y.-Y. Lin and Y.-H. Liao contributed methodology-experimental resources; Y.-Y. Lin and C. Chen performed methodology; Y.-Y. Lin and K. Masodsai contributed data curation; Y.-Y. Lin and Y.-H. Liao contributed original draft; Y.-Y. Lin and K. Masodsai contributed editing and revising the manuscript. All authors approved the final version of the manuscript.

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