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The effects on mental fatigue and the cognitive function of mechanical massage and binaural beats (brain massage) provided by massage chairs

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ABSTRACT

Objective: To verify whether the mechanical massage using massage chairs and binaural beats (brain massage) affect the mental fatigue recovery and cognitive enhancements.

Methods: 25 healthy adults used massage chairs that could provide mechanical massage and binaural beats (brain massage) for 20 min. Mental fatigue and cognitive function were assessed before and after receiving brain massage using electroencephalogram (EEG) and 5 prolonged cognitive tests.

Results: When a person received a brain massage on the massage chair, the decrease in mental fatigue was statistically significant compared to taking a rest or receiving a mechanical massage only on the massage chair. In addition, sustained attention, verbal short-term and long-term memory and non-verbal long-term memory were statistically significantly increased after using brain massage.

Conclusion: Brain massage (mechanical massage and binaural beats) are effective in reducing mental fatigue and improving the cognitive function.

1. Introduction

As times change, mental labor has been increasingly required in modern society. Accordingly, mental fatigue can be more easily experienced in everyday life [1]. Mental fatigue refers to the feeling of fatigue and exhaustion, which can be experienced during or after prolonged cognitive activity and is known to be associated with sympathetic hyperactivity [2]. The accumulation of mental fatigue causes a decrease in individual cognitive functions, and Van der Linden et al. (2003a, 2003b, 2006) have reported that planning and eventual strategic modification are difficult because of mental fatigue [3–5]. In addition, Boksem et al. (2005) reported that mental fatigue made it difficult to ignore irrelevant information to the task currently being performed [6]. This decline in cognitive functions affects both individuals and society. According to the research conducted by Ricci et al., approximately 66% of the workforce declines in productivity in the comparison between those who are tired and those who are not tired, which caused an annual social cost of more than $100 billion in the United States alone [7]. Thus, it is notably important to improve the cognitive functions through recovering mental fatigue.

Massage is one of the commonly used alternative treatments for fatigue recovery purposes, which tap or knead the body's muscles and joints by hands or tools [8–10]. According to previous studies, the stimulus to skin and muscles through massage activates the sensory, temperature, vibration, and pain receptors, is transferred to the autonomic and central nervous system and triggers neuro-chemical reactions [11,12]. As a result, the hyper-activated nervous system is stabilized, and the parasympathetic nervous system is activated, which reduces the blood pressure, pulses and cortisol levels, relaxes one's mind and body, and helps recovering from fatigue [11,12]. Massage also affects the cognitive functions: 15 min of massage improve math calculations [13], and massage using a stream of water improves the working memory, which is related to restoring, planning and execution of information [14]. The effect of massage on the mental fatigue recovery appears to improve the cognitive functions.

The public interest in massage chairs is rapidly increasing with the efficacy of these massages and the healing trends of modern people seeking comfort, healing and mental health [15]. A massage chair is a chair-type massager that uses mechanical tools such as massage balls, rollers and airbags to automatically massage the user's full body. With the advances in technology, recent massage chairs can implement a professional's feeling of massage such as tapping, kneading and acupressure [15]. Thus, the effectiveness of massage chairs are expected to be similar to the effectiveness of the massage itself. However, there are few studies except for massage chair's effects on inducing muscle's relaxation [16] and sleep [17], so further studies of the clinical effectiveness of massage chairs are necessary.

In addition, the modern massage chairs offer music therapy such as

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instrumental music, natural sounds and binaural beats for relaxation and refresh. The binaural beats refer to the third sound heard when two different frequencies of pure tones are provided in each ear [18]. For example, when a pure tone of 295 Hz is heard through the left ear and a pure tone of 305 Hz is heard through the right ear, the beat sound of 10 Hz can be heard, which entrains the 10-Hz brainwaves and regulates the autonomic nervous system [18]. According to previous studies, the binaural beats have a positive effect on the blood pressure, pulse rate, body temperature, emotion, relaxation, and cognitive functions [16,19–24]. Thus, mechanical massage and binaural beats have different mechanisms but seem to have similar positive effects. However, there is no evidence that these effects of mechanical massage and binaural beats have relieved mental fatigue and improved cognitive functions such as concentration and memory.

Therefore, this study intends to verify whether the mechanical massage using massage chairs and the binaural beats (brain massage) are effective for mental fatigue recovery and cognitive functions enhancement. For this purpose, prolonged cognitive tests were conducted for healthy adults, which induced mental fatigue, and the massage chairs that could provide mechanical massage and binaural beats were used. Furthermore, by quantitatively analyzing the electroencephalogram (EEG) and cognitive tests results, we objectively verified the decrease in mental fatigue and improvement in cognitive function.

2. Material and methods

2.1. Participants and overall experimental paradigm

This study was conducted on 25 healthy volunteers of 20–50 years old, who agreed to voluntarily participate in the experiment. All subjects had no neurological or psychiatric history and previously confirmed that they did not have any disease that could affect the results of the experiment. Each subject was fully informed of the details of the experimental procedure, and all participants were given written consent to participate in the experiment. The study was reviewed and approved by the Public Institutional Review Board (IRB) committee designated by the Ministry of Health and Welfare, Korea (IRB approval number: P01-201706-11-001).

The overall experimental procedure is shown in Fig. 1. To verify the effects of receiving a mechanical massage and listening to the binaural beats using the massage chair (Treatment C) on the mental fatigue recovery and cognitive improvement, two treatments were selected as the control: having a rest while sitting on a massage chair (Treatment A) and receiving a mechanical massage with a massage chair (Treatment B). The experiment was performed according to a single-group crossover design, so all 25 participants received treatment A, B and C once. In order to minimize the effect of each treatment order, only one type of treatment was given per day, and the order of the treatments was determined by 6-block randomization. Each treatment lasted for 20 min, and the participants took at least 3 weeks to receive all the treatments because the time interval between each treatment was at least one week. Electroencephalogram (EEG) recording and cognitive tests were performed once before and after each treatment.

2.2. Description of each treatment

In this study, we used a massage chair (Bodyfriend Inc., Seoul, Korea) with 2 massage arms, 40 airbags and 4 rollers, which could massage the entire body including the neck, shoulders, arms, hands, waist, hip, calf, and sole. The massage chair has a built-in automatic mode that massages the entire body of the user in a specific pattern. It mainly uses 19–33 kneadings, 298–530 tappings per minute, and soft acupressure patterns. The basic angle of the backrest of the massage chair and the ground is 135° and is adjustable. Two separate stereo speakers are located on both sides of the user's ear to play various sound sources such as binaural beats.

Table 1 shows the detailed parameters such as the massage method, massage area, and massage chair angle for each treatment. In Treatment A, the backrest angle of the massage chair was laid down at approximately 160°, which enabled the subject to rest in a relaxed posture for 20 min without mechanical massage. In Treatment B, the “Concentration” massage mode was used to massage the subject's body for 20 min in a specific pattern. First, the backrest angle of the massage chair was laid down at approximately 150°, and the whole-body acupressure and kneading were repeated for 5 min. Then, the massage chair was laid down at 170°, the legs were positioned higher than the head, and the neck and waist were slowly kneaded or received acupressure for 10 min. In the last 5 min, the massage chair was raised again to 135°, and the subject was awaken by acupressure, kneading, and tapping to the entire body. In Treatment C, the massage pattern was identical to that in treatment B, while piano music, natural sounds such as valley water, and binaural beats (brain massage) were provided for 20 min. The beat frequency of the binaural beats was changed to 10, 7, 4, and 10 Hz at 5-min intervals.

2.3. EEG data acquisition and analysis

In this study, electroencephalogram (EEG) signals were measured using a multi-channel EEG (QEEG-64FX, Laxtha Inc., Daejeon, Korea) to

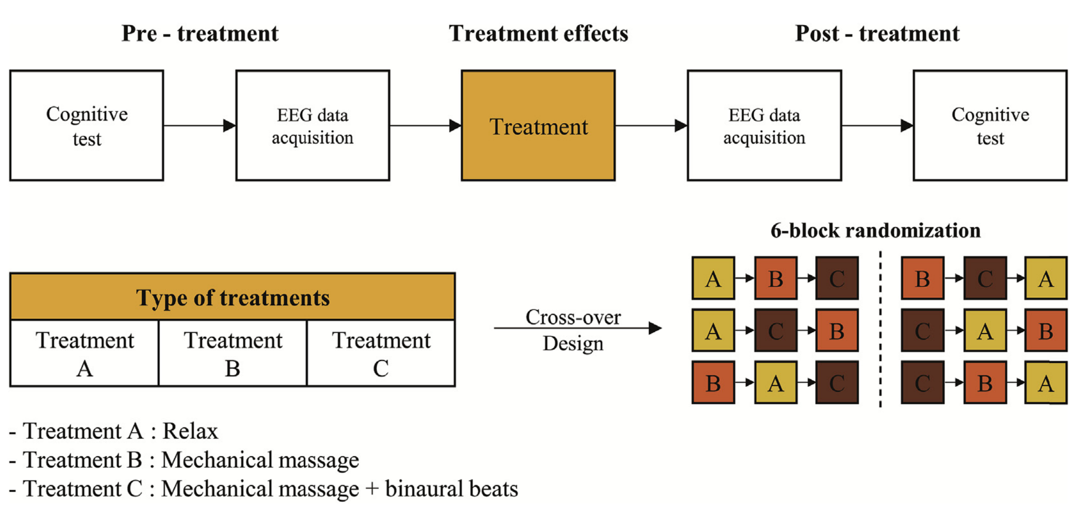

Fig. 1. Overall experimental procedure. The experiment was performed according to the cross-over design, and the treatment order was determined by 6-block randomization. EEG recording and cognitive tests were performed once before and after each treatment.

Table 1
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Treatments	Phases	Duration (min.)	Types of mechanical massage	Massage areas	Frequencies of the binaural beats	Angles
A	1	20	–	–	–	
B	1	5	kneading, acupressure	whole-body	–	
	2	10	slow kneading, acupressure	neck, waist		
	3	5	kneading, acupressure, tapping	whole-body		
C	1	5	kneading, acupressure	whole-body	10 Hz	
	2	10	slow kneading, acupressure	neck, waist	7 Hz → 4 Hz	
	3	5	kneading, acupressure, tapping	whole-body	10 Hz	

Fig. 2. Snapshot of the EEG measurement. The EEG signals were measured using six electro-conductive Ag/AgCl electrodes (Fp1, Fp2, F3, F4, AF7, AF8) while the subject was sitting on a massage chair.

quantitatively assess the subject's mental fatigue, as shown in Fig. 2. Six electro-conductive Ag/AgCl electrodes (Fp1, Fp2, F3, F4, AF7, and AF8) were attached to the prefrontal cortex for the EEG measurement. Ground and reference electrodes were attached to the left and right mastoids, respectively. The EEG was recorded for 3 min while the subject was sitting comfortably on the massage chair with closed eyes. A low-pass filter with a cutoff frequency of 0.5 Hz and a high-pass filter with a cutoff frequency of 50 Hz were used, and the digital sampling frequency was 1 kHz.

The measured EEG signal is a weak signal in micro volts and easily affected by physiological noise such as electrooculography (EOG), electromyogram (EMG), and environmental noise from the external environment. To eliminate this noise, the baseline correction was performed using the average value of the measured data at each EEG electrode; then, a 3-order band-pass filter of 0.1–50 Hz frequency was applied. In addition, the MSDW (multi-summation of derivatives within a window) algorithm was used to exclude the noise derived from eye movements such as saccades or slow eye movements [25].

To measure the subject's mental fatigue, the power value of each frequency band was obtained from the noise-canceled EEG signal. For this purpose, the 3-min EEG signal with noise removed was divided by 2-s epochs with 90% overlapping, a Hamming window was applied to each epoch, and a fast Fourier transform (FFT) was calculated. The mean power values of theta (3–9 Hz), alpha (9–13 Hz) and beta (13–30 Hz) were calculated by averaging the power values for each frequency band of the epoch. The powers of theta/beta and (theta + alpha)/beta, which have been used in many previous studies, were calculated and used as a mental fatigue index [26]. Then, differences in mental fatigue index values before and after each treatment were calculated to compare the decrease in mental fatigue of each treatment.

2.4. Cognitive tests

The cognitive tests consist of tests to evaluate the cognitive functions of the subject, such as attention and memory, and tests to induce mental fatigue to the subjects. The time required to perform each test was approximately 40 min, and all tests were conducted with no breaks.

2.4.1. d2-test

The d2-test is one of the neuropsychological tests that have been used to evaluate the visual scanning speed and sustained attention [27]. In the paper-based test, there are 15 character lines with 50 character on a paper. Each character consists of a combination of alphabetic letters ("d" or "p") and 0–2 ″dots" above or below each letter. In this experiment, we modified the test to increase the difficulty level. The target character to be removed by the subject consisted of alphabetic letter "d", the number of "dots" above and below was 2 or 3, and the total number of targets in one character line was 25. The subjects should solve one character line for 15 s; as soon as the time period

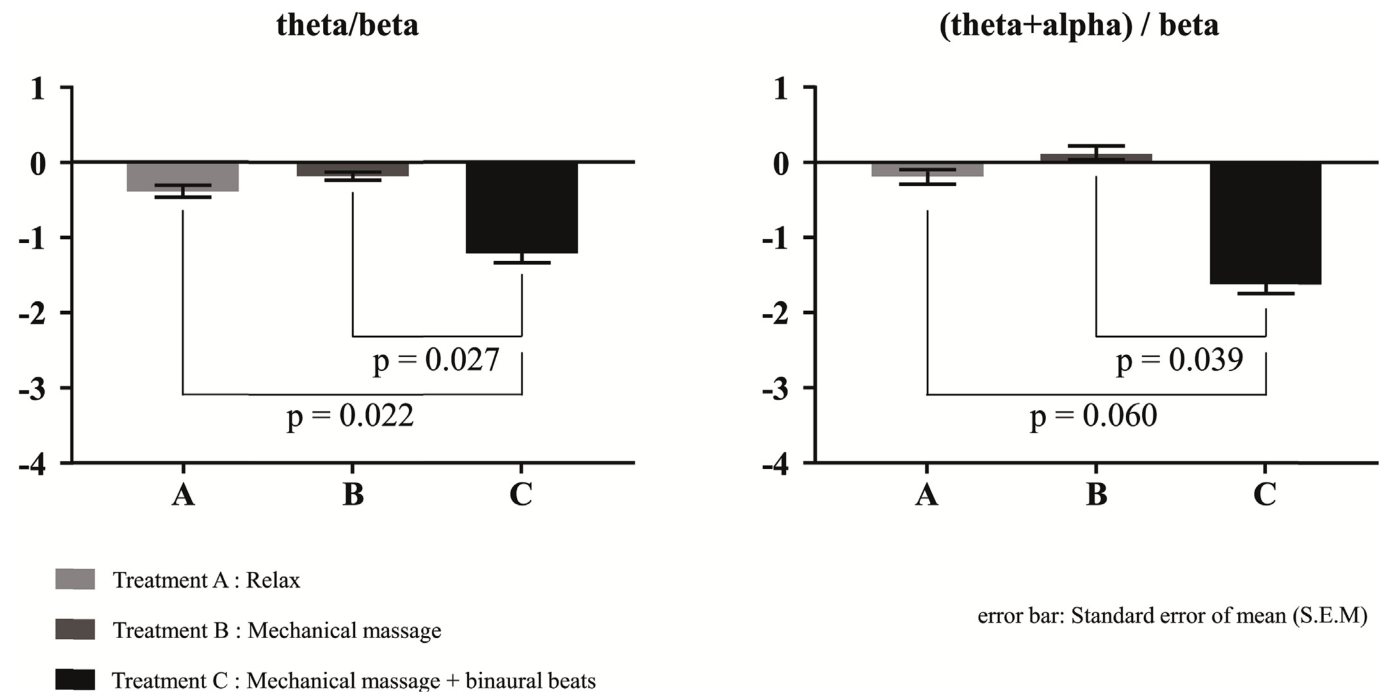

Fig. 3. Mean decrease in mental fatigue before and after each treatment A, B and C using the decrease in theta/beta and (theta + alpha)/beta indices. There was a statistically significant difference in the mental fatigue reduction among the treatments using each index (theta/beta index: $p = 0.027$, $F = 4.017$; (theta + alpha)/beta index: $p = 0.044$, $F = 3.407$). The post-analysis shows that Treatment C reduced significantly more mental fatigue than treatments A and B.

ended, they should solve the next character line to maintain attention without rest. After sufficient practice for the subjects to adapt to the test method, the main test was repeated four times without rest for 15 min to induce mental fatigue. The subject's attention performance was measured by subtracting the number of type-II errors from the number of correctly removed targets. To assess the sustained attention, the first test score among the 4 tests performed before the treatment was used as the baseline, and the trend of concentration was observed using the 4 test scores performed after the treatment.

2.4.2. Digit span test

The digit span test was used to assess the subject's verbal short-term memory. A typical method of Wechsler Memory Scale-Revised (WMS-R) was used [28]. In this test, 3 random single digits are consecutively shown on a monitor placed in front of the subject. The subject memorizes and speaks the combination of these numbers. Whenever the subject correctly speaks the number, the number of the displayed digit on the monitor increases by one. When the subject is wrong twice at the identical number of the digit, the experiment is terminated, and the number of digits immediately before the end of the experiment is the score of this test. The identical method was used before and after the treatment, and the test scores were compared.

2.4.3. Corsi block-tapping test

Corsi block-tapping test was used to assess the subject's nonverbal short-term memory. A typical method of Wechsler Memory Scale-Revised (WMS-R) was used [28]. In this test, 10 rectangular blocks are randomly placed on a monitor in front of the subject and blinked in a random order. The number of times that the block is blinking begins at 3; whenever the subject correctly memorizes the blinking order, the number is increased by one. When the subject is wrong twice at the identical number of the blinking orders, the experiment is terminated, and the number of orders immediately before the end of the experiment is the score of this test. The identical method was used before and after the treatment, and the test scores were compared.

2.4.4. Picture recognition test

The picture recognition test was used to assess the verbal long-term memory. A typical method of the Rivermead Behavioral Memory Test (RBMT) was used [29]. In this test, the subject is shown 20 individual objects and background pictures at intervals of 2 s one at a time on the monitor. Then, 10 randomly selected target pictures are displayed one by one at intervals of 2 s, so that the subjects can memorize them. After 5 min, the subject is shown the first 20 pictures one by one and asked to select a memorized target picture among them. The test score is obtained by subtracting the incorrect number from the number of pictures that the subject successfully memorizes. The identical method was used before and after the treatment, and the test scores were compared.

2.4.5. Face recognition test

The face recognition test was used to assess the nonverbal long-term memory. A typical method of the Rivermead Behavioral Memory Test (RBMT) was used [29]. In this test, the subject is shown 10 face pictures at intervals of 2 s one at a time on the monitor. Then, 5 randomly selected target pictures are displayed at intervals of 2 s one by one, so that the subjects can memorize them. After 5 min, the subject is shown the first 10 pictures one by one and asked to select a memorized target picture among them. The test score is obtained by subtracting the incorrect number from the number of pictures that the subject successfully memorizes. The identical method was used before and after treatment, and the test scores were compared.

2.5. Statistical analysis

The collected data were analyzed using the SPSS WIN version 12.0 (SPSS Inc, Chicago, IL, USA) program as follows. First, if the power value of each EEG frequency band and each cognitive test score were outside the range from (average–2 × standard deviation) to (average + 2 × standard deviation), the subject was considered an outlier and excluded from the data analysis. The difference in mental fatigue change derived from the EEG indices between each treatment was confirmed using the repeated measures analysis of variance

(ANOVA) with a significance level of 0.05. Bonferroni multiple comparisons were performed in the post-analysis. To compare the cognitive function test results before and after each treatment, the paired *t*-test was used when the data were normalized using Kolmogorov-Smirnov test; otherwise, Wilcoxon signed rank test was used.

3. Results

3.1. Results of mental fatigue using the EEG indices

Fig. 3 shows the mean decrease in mental fatigue before and after each treatment A, B, and C using the decrease in theta/beta and (theta + alpha)/beta indices (error bar: Standard error of mean (SEM)). The statistical analysis results show a statistically significant difference in the mental fatigue reduction among the treatments using each index (theta/beta index: $p = 0.027$, $F = 4.017$; (theta + alpha)/beta index: $p = 0.044$, $F = 4.307$). The post-analysis shows no significant difference in the theta/beta index between treatments A and B ($p = 0.620$). Treatment C had significantly higher mental fatigue reduction than treatments A and B ($p = 0.022$, 0.027). In the (theta + alpha)/beta index, there was no difference between treatments A and B ($p = 0.655$), and Treatment C had marginally and significantly higher mental fatigue reduction than treatments A and B ($p = 0.060$, 0.039).

Table 2 shows the statistical significance of the theta/beta and (theta + alpha)/beta indices values from 6 electrodes before and after each treatment. In treatment C, there was a significant difference before and after the treatment in most electrodes except Fp1 and F4 ($p < 0.05$), but there was no difference before and after treatments B and C ($p > 0.05$). The mean value of each index for all electrodes was also significantly different before and after treatment C (theta/beta: $p = 0.003$; (theta + alpha)/beta: $p = 0.019$), but there was no significant difference before and after treatments A and B ($p > 0.05$).

3.2. Results of the cognitive test

Fig. 4 shows the d2-test score trends for pre-treatment (pre) and 4 consecutive post-treatment (post (1) ~ post (4)). Table 3 shows the statistical comparison results of the d2-test for each pre- and 4 consecutive post-treatments. In Fig. 4, compared to the pre-treatment, the d2-test scores significantly increased immediately after treatments A, B, and C ($p < 0.001$). In Table 3, although the d2-test scores for 4 consecutive post-treatment B and C were significantly higher than the pre-treatment values ($p < 0.05$), there was no significant difference between pre-treatment and post-treatment (3) and (4) in treatment A (post-treatment (3): $p = 0.229$; post-treatment (4): $p = 0.102$).

Table 2
Statistical significance of the theta/beta and (theta + alpha)/beta indices from 6 electrodes before and after each treatment. In treatment C, there was a significant difference before and after the treatment in most electrodes.

Parameters	Channels	Type of treatment (p-values)		
		A	B	C
theta/beta	Fp1	0.813	0.149	0.064
	Fp2	0.494	0.570	**0.006**
	F3	0.420	0.293	**0.010**
	F4	0.248	0.873	**0.039**
	AF7	0.734	0.087	**0.039**
	AF8	0.434	0.414	**0.008**
	Average	0.290	0.465	**0.003**
(theta + alpha)/beta	Fp1	0.630	0.430	0.053
	Fp2	0.716	0.528	**0.036**
	F3	0.807	0.660	**0.032**
	F4	0.370	0.865	0.065
	AF7	0.637	0.127	**0.045**
	AF8	0.631	0.286	**0.008**
	Average	0.679	0.805	**0.019**

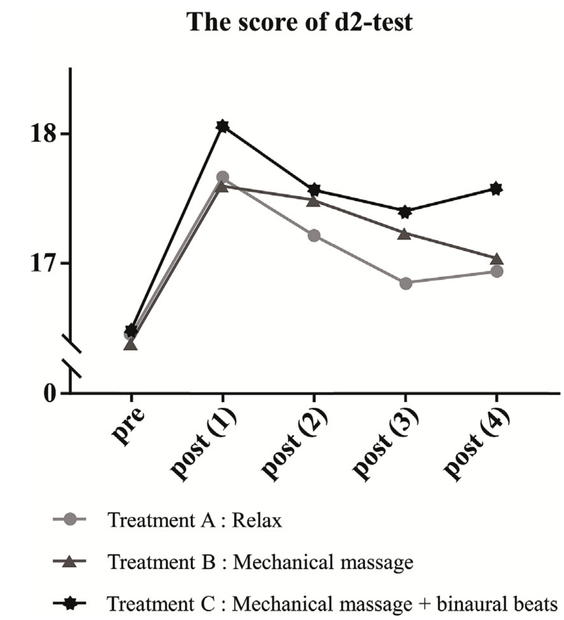

Fig. 4. d2-test score trends for pre-treatment (pre) and 4 consecutive post-treatments (post (1) ~ post (4)). The d2-test scores significantly increased immediately after treatments A, B and C ($p < 0.001$).

Table 3
Statistical comparison results of d2-test scores for each pre-treatment and 4 consecutive post-treatments. The d2-test scores for 4 consecutive post-treatment B and C were significantly higher than the pre-treatment values, but there was no significant difference between pre-treatment and post-treatment (3) and (4) in treatment A.

Comparisons with pre-treatment	Type of treatments (p-values)		
	A	B	C
Post-treatment (1)	**0.000**	**0.000**	**0.000**
Post-treatment (2)	**0.011**	**0.002**	**0.000**
Post-treatment (3)	0.229	**0.006**	**0.003**
Post-treatment (4)	0.102	**0.041**	**0.001**

Fig. 5 shows the cognitive test scores before and after each treatment, and Table 4 shows the statistical comparison of the cognitive test scores (error bar: Standard error of mean (SEM)). The digit span test scores significantly increased only after treatment C ($p = 0.006$), whereas treatments A and B did not cause a difference from the values before and after treatment ($p = 0.116$, 0.186). The corsi block-tapping test scores showed no difference after treatments A, B and C ($p = 0.336$, 0.741, 0.572). The picture recognition test scores significantly increased only after treatment C ($p = 0.041$), whereas treatments A and B did not cause a difference before and after the treatment ($p = 0.324$, 0.916). The face recognition test scores significantly increased after treatments B and C ($p = 0.001$, 0.032), but treatment A induced no difference before and after the treatment ($p = 0.250$).

4. Discussion

The massage has been proven to be effective for fatigue recovery, various types of pain reduction, such as fibromyalgia, rheumatoid arthritis, weight gain improvement, depression relief, immunity enhancement, and cognitive improvement [30]. Based on these findings, mechanical massage using massage chair has been estimated to have clinical effect, but the clinical effect has not been objectively verified except for studies on the reduction of muscle tension [16] and improvement of sleep quality [17]. This study is the first attempt to investigate the effect of mechanical massage and binaural beats (brain

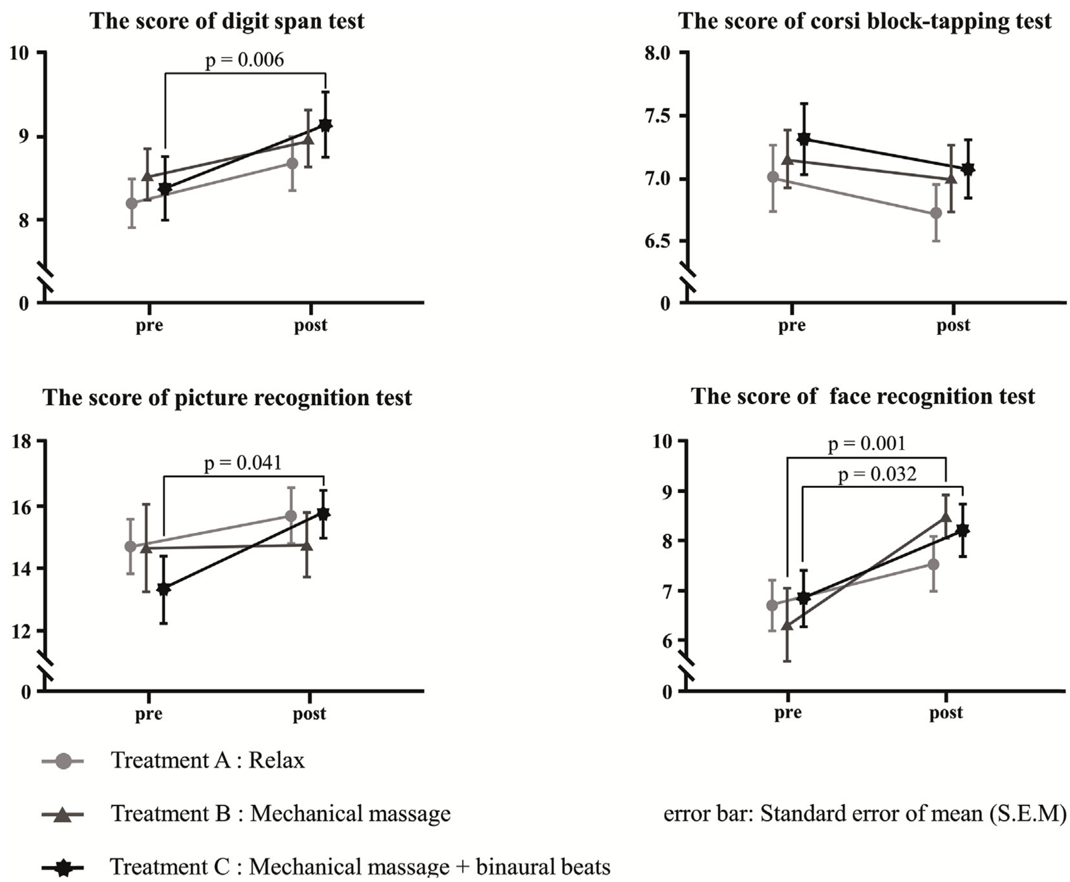

Fig. 5. Cognitive test scores before and after each treatment. The statistical comparison results show that the digit span test scores only significantly increased after treatment C ($p = 0.006$), the corsi block-tapping test scores did not vary in treatments A, B and C, the picture recognition test scores only significantly increased after treatment C ($p = 0.041$), and the face recognition test scores significantly increased after treatments B and C ($p = 0.001$, 0.032).

Table 4
Statistical comparison results of the cognitive test scores before and after the treatments.

Cognitive test	Type of treatments (p-values)		
	A	B	C
Digit span test	0.116	0.186	**0.006**
Corsi block-tapping test	0.336	0.741	0.572
Picture recognition test	0.324	0.916	**0.041**
Face recognition test	0.250	**0.001**	**0.032**

massage) using massage chairs on mental fatigue and cognitive function. In addition, it is significant in that the brain massage positively affect the mental fatigue recovery and cognitive functions such as attention and memory.

Although this study used the cross-over design of random order, the blind test could not be performed because the subject could know the applied treatment. Therefore, mental fatigue was objectively quantified using the frequency power spectrum analysis of EEG instead of a subjective method such as a survey. EEG is mainly divided into frequency bands such as delta (0–4 Hz), theta (3–9 Hz), alpha (9–13 Hz), and beta (13–30 Hz). The low-frequency band is known to be related to the deep sleep, and the higher-frequency band is related to arousal, excitement, and concentration state [31]. In particular, theta increases in the early stages of sleepiness [32]; alpha increases when one is comfortably resting or the concentration is low [33]; beta increases during tense moments or concentration [34]. This classification indicates that mental fatigue can be quantified using changes in EEG such as an increase in alpha and theta and a decrease in beta. The theta/beta and (theta + alpha)/beta indices are used in this study as indicators, which were also used in previous literature on mental fatigue. According to the studies, when the mental fatigue increases because of long driving, the index value is significantly increased [26,34,35]. Thus, a significant decrease in indices after treatment C indicates that the mechanical massage and binaural beats reduce mental fatigue.

The results of this study confirm that the mechanical massage of the massage chair and binaural beats improve the sustained attention, nonverbal long-term memory and verbal short- and long-term memory via mental fatigue recovery. Interestingly, the use of only the mechanical massage of a massage chair improved the sustained attention and nonverbal long-term memory, though the mental fatigue level did not decrease. According to the research conducted by Field et al., it seems to be caused by massage mechanism, in which the stimulation of the peripheral nerves through massage enhances the activity of the vagus nerve and septo-hippocampal nerves [8]. As a result, the massage affects the cognitive function such as mathematical ability and memory [13,14] and improve the symptoms of patients with cognitive impairment such as dementia. Previous studies stated that the abnormal symptoms of dementia patients such as violence and anxiety were improved [36–39], and the short-term and long-term memory were increased [40].

With the aforementioned massage mechanism, the binaural beats also has a large impact on the cognitive function. When both ears are accompanied by two pure-tone sounds of different frequencies, the phase-sensitive neuron in the inferior colliculus is stimulated along the auditory pathway, and the beat sound is recognized in the superior olivary complex [21,41]. Simultaneously, the frontal and parietal regions associated with cognitive function in the brain are activated, and the functional connectivity is increased [42], which enhances the concentration [43–45] and verbal memory [42,43,46]. We believe that this effect of the binaural beats is synergistic with the mechanical massage of the massage chair, which makes the cognitive test result meaningful.

In this study, we have examined how much fatigue is restored after mental fatigue is provided to healthy people and how it affects the cognitive function. Therefore, patients with chronic fatigue, who are always tired, cannot be sure of their effects on the mechanical massage and binaural beats. In addition, it is difficult to be sure that the cognitive function will improve for patients with cognitive impairment such as dementia or Attention Deficit Hyperactivity Disorder (ADHD). Nonetheless, even with a single 20-min use, the mechanical massage and binaural beats restore the mental fatigue and improve cognitive function. Therefore, subsequent studies on these patients are expected to show improvement effects.

Conflicts of interest

All authors wish to indicate that they are employed by the Bodyfriend, the organization that supports this study.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ctcp.2018.04.008.

References

[1] M.A.S. Boksem, M. Tops, Mental fatigue: costs and benefits, Brain Res. Rev. 59 (1) (2008) 125–139.
[2] K. Mizuno, M. Tanaka, K. Yamaguti, O. Kajimoto, H. Kuratsune, Y. Watanabe, Mental fatigue caused by prolonged cognitive load associated with sympathetic hyperactivity, Behav. Brain Funct. 7 (2011) 1–17.
[3] D. van der Linden, M. Frese, T.F. Meijman, Mental fatigue and the control of cognitive processes: effects on perseveration and planning, Acta Psychol. (Amst.) 113 (1) (2003) 45–65.
[4] D. van der Linden, M. Frese, S. Sonnentag, The impact of mental fatigue on exploration in a complex computer task: rigidity and loss of systematic strategies, Hum. Factors 45 (3) (2003) 483–494.
[5] D. van der Linden, P. Eling, Mental fatigue disturbs local processing more than global processing, Psychol. Res. 70 (5) (2006) 395–402.
[6] M.A.S. Boksem, T.F. Meijman, M.M. Lorist, Effects of mental fatigue on attention: an ERP study, Cognit. Brain Res. 25 (1) (2005) 107–116.
[7] J.A. Ricci, E. Chee, A.L. Lorandeau, J. Berger, Fatigue in the US workforce: prevalence and implications for lost productive work time, J. Occup. Environ. Med. 49 (1) (2007) 1–10.
[8] T. Field, M. Diego, M. Hernandez-Reif, Massage therapy research, Dev. Rev. 27 (1) (2007) 75–89.
[9] T.M. Field, Massage therapy effects, Am. Psychol. 53 (12) (1998) 1270–1281.
[10] C.A. Moyer, J. Rounds, J.W. Hannum, A meta-analysis of massage therapy research, Psychol. Bull. 130 (1) (2004) 3–18.
[11] G.C. Goats, Massage - the scientific basis of an ancient-art .2. Physiological and therapeutic effects, Br. J. Sports Med. 28 (3) (1994) 153–156.
[12] M.H. Rapaport, M.A. Koury, K.L. Hale, C.J. Bresee, The beneficial effects of massage therapy on psychiatric and biological measures, Biol. Psychiatr. 61 (8) (2007) 27S-27S.
[13] T. Field, G. Ironson, F. Scafidi, T. Nawrocki, A. Goncalves, I. Burman, Massage therapy reduces anxiety and enhances EEG pattern of alertness and math computations, Int. J. Neurosci. 86 (3–4) (1996) 197–205.
[14] K. Mizuno, M. Tanaka, K. Tajima, N. Okada, K. Rokushima, Y. Watanabe, Effects of mild-stream bathing on recovery from mental fatigue, Med. Sci. Mon. Int. Med. J. Exp. Clin. Res. 16 (1) (2010) CR8–CR14.
[15] K.-B. Kim, A market status of message chair and technical analysis of future it convergence, J. Kor. Converg. Soc. 6 (3) (2015) 29–36.
[16] D.F. Zullino, S. Krenz, E. Fresard, E. Cancela, Y. Khazaal, Local back massage with an automated massage chair: general muscle and psychophysiologic relaxing properties, J. Alternative Compl. Med. 11 (6) (2005) 1103–1106.
[17] S.J. Choi, S.H. Yun, E.Y. Joo, Effects of electrical automatic massage of whole body at bedtime on sleep and fatigue, J. Sleep Med. 14 (1) (2017) 10–17.
[18] G. Oster, Auditory beats in the brain, Sci. Am. 229 (4) (1973) 94–102.
[19] J.D. Lane, S.J. Kasian, J.E. Owens, G.R. Marsh, Binaural auditory beats affect vigilance performance and mood, Physiol. Behav. 63 (2) (1998) 249–252.
[20] S.A. Reedijk, A. Bolders, B. Hommel, The impact of binaural beats on creativity, Front. Hum. Neurosci. 7 (2013).
[21] D.W.F. Schwarz, P. Taylor, Human auditory steady state responses to binaural and monaural beats, Clin. Neurophysiol. 116 (3) (2005) 658–668.
[22] L. Stevens, Z. Haga, B. Queen, B. Brady, D. Adams, J. Gilbert, E. Vaughan, C. Leach, P. Nockels, P. McManus, Binaural beat induced theta EEG activity and hypnotic susceptibility: contradictory results and technical considerations, Am. J. Clin. Hypn. 45 (4) (2003) 295–309.
[23] J.V. Tobias, Application of a relative procedure to a problem in binaural-beat perception, J. Acoust. Soc. Am. 35 (9) (1963) 1442.
[24] H. Wahbeh, C. Calabrese, H. Zwickey, D. Zajdel, Binaural beat technology in humans: a pilot study to assess neuropsychologic, physiologic, and electroencephalographic effects, J. Alternative Compl. Med. 13 (2) (2007) 199–206.
[25] W.D. Chang, H.S. Cha, K. Kim, C.H. Im, Detection of eye blink artifacts from single prefrontal channel electroencephalogram, Comput. Meth. Progr. Biomed. 124 (2016) 19–30.
[26] B.T. Jap, S. Lal, P. Fischer, E. Bekiaris, Using EEG spectral components to assess algorithms for detecting fatigue, Expert Syst. Appl. 36 (2) (2009) 2352–2359.
[27] M.E. Bates, E.P. Lemay, The d2 Test of Attention: construct validity and extensions in scoring techniques, J. Int. Neuropsychol. Soc. 10 (3) (2004) 392–400.
[28] G.P. Prigatano, Wechsler memory scale - selective review of literature, J. Clin. Psychol. 34 (4) (1978) 816–832.
[29] D. Towle, C.R. Wilsher, The rivermead behavioral memory test - remembering a short route, Br. J. Clin. Psychol. 28 (1989) 287–288.
[30] T. Field, Massage therapy research review, Compl. Ther. Clin. Pract. 20 (4) (2014) 224–229.
[31] D. Mantini, M.G. Perrucci, C. Del Gratta, G.L. Romani, M. Corbetta, Electrophysiological signatures of resting state networks in the human brain, Proc. Natl. Acad. Sci. U. S. A 104 (32) (2007) 13170–13175.
[32] T. Akerstedt, M. Gillberg, Subjective and objective sleepiness in the active individual, Int. J. Neurosci. 52 (1–2) (1990) 29–37.
[33] J.M. Stern, J. Engel, Altas of EEG Patterns, Lippincott Williams & Wilkins, USA, 2005.
[34] H.J. Eoh, M.K. Chung, S.H. Kim, Electroencephalographic study of drowsiness in simulated driving with sleep deprivation, Int. J. Ind. Ergon. 35 (4) (2005) 307–320.
[35] K.A. Brookhuis, D. Dewaard, The use of psychophysiology to assess driver status, Ergonomics 36 (9) (1993) 1099–1110.
[36] D.J.R. Brooker, M. Snape, E. Johnson, D. Ward, M. Payne, Single case evaluation of the effects of aromatherapy and massage on disturbed behaviour in severe dementia, Br. J. Clin. Psychol. 36 (1997) 287–296.
[37] E.J. Kim, M.T. Buschmann, The effect of expressive physical touch on patients with dementia, Int. J. Nurs. Stud. 36 (3) (1999) 235–243.
[38] M. Snyder, E.C. Egan, K.R. Burns, Efficacy of hand massage in decreasing agitation behaviors associated with care activities in persons with dementia, Geriatr. Nurs. 16 (2) (1995) 60–63.
[39] K. Yoshiyama, H. Arita, J. Suzuki, The effect of aroma hand massage therapy for people with dementia, J. Alternative Compl. Med. 21 (12) (2015) 759–765.
[40] E. Scherder, A. Bouma, L. Steen, The effects of peripheral tactile stimulation on memory in patients with probable Alzheimer's disease, Am. J. Alzheimers Dis. 10 (1995) 15–21.
[41] S. Kuwada, T.C.T. Yin, R.E. Wickesberg, Response of cat inferior colliculus neurons to binaural beat stimuli - possible mechanisms for sound localization, Science 206 (4418) (1979) 586–588.
[42] C. Beauchene, N. Abaid, R. Moran, R.A. Diana, A. Leonessa, The effect of binaural beats on verbal working memory and cortical connectivity, J. Neural. Eng. 14 (2) (2017).
[43] N. Jirakittayakorn, Y. Wongsawat, Brain responses to 40-Hz binaural beat and effects on emotion and memory, Int. J. Psychophysiol. 120 (2017) 96–107.
[44] V.D. Cruceanu, V. Rotarescu, Alpha brainwave entrainment as a cognitive performance activator, Cogn. Brain Behav. 17 (2013) 249–261.
[45] L.S. Colzato, H. Barone, R. Sellaro, B. Hommel, More attentional focusing through binaural beats: evidence from the global-local task, Psychol. Res. 81 (1) (2017) 271–277.
[46] T. Ortiz, A.M. Martinez, A. Fernandez, F. Maestu, P. Campo, R. Hornero, J. Escudero, J. Poch, Impact of auditory stimulation at a frequency of 5 Hz in verbal memory, Actas Esp. Psiquiatr. 36 (6) (2008) 307–313.