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The Effect of Brief, Low-Intensity Stretching Gymnastics on Autonomic Nervous System Activity and Cognitive Function

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Abstract

Purpose: Stretching exercise and gymnastics both have beneficial effects, such as improvement of autonomic nervous system activity and mood. Additionally, studies on the effects of exercise on cognitive function have been conducted covering a wide range of age groups and have attracted much attention. However, conventional studies have set up programs with implementation times of 20 to 30 minutes. Therefore, shorter stretching programs are needed in order to fit them more easily into one's free time. We examined the effects of a short 7-minute stretching gymnastics regime on the autonomic nervous system activity and cognitive function in 21 healthy participants. **Methods:** In this study, the participants performed a 10-minute cognitive task, followed by either Stretch Well Gymnastics, Stretch Band Gymnastics, or Radio Gymnastics sessions on different days. The participants then performed the cognitive task again. Heart rate was measured continuously throughout the experiment and we analyzed the heart rate variability. The cognitive tasks completed by all of the participants were evaluated for inhibitory control and cognitive flexibility. **Results:** A significant increase was shown in the sympathetic nerve activity during the Stretch Well Gymnastics, compared to the Radio Gymnastics and Stretch Band Gymnastics. Parasympathetic nerve levels were significantly increased after the gymnastics, compared to during the gymnastics, although there were no significant differences between any of the tasks. Additionally, in both the Stroop task and the number-Letter task, reaction times were faster in all of the sessions. In particular, the Stroop task showed the highest values for the Radio Gymnastics sessions, with marginally significantly lower scores for the Stretch Well Gymnastics sessions. **Conclusion:** The results showed that these heart rate variability responses supported the effects of autonomic activity associated with conventional low-intensity exercise. Additionally, stretching gymnastics for less than

10 minutes showed a positive effect on inhibitory function and cognitive flexibility.

Keywords

Stretching Gymnastics, Autonomic Nervous System, Cognitive Function, Stretch Well Gymnastics

1. Introduction

The objective effect of mild-to-moderate intensity exercise on positive mental health can be seen from physiological indices. Studies focusing on the autonomic nervous system function have shown that the sympathetic nervous system is activated during exercise and the parasympathetic nervous system is activated after exercise. For example, it has been reported that at the onset of exercise, the parasympathetic nervous system is inhibited before the sympathetic nervous system is excited [1]. It has also been shown that light-intensity exercise results in more rapid recovery of the parasympathetic nervous system during the post-exercise recovery period, compared with high-intensity exercise [2].

While verification of the effects of the autonomic nervous system activity associated with such exercise has been conducted in the past, recent studies showing the effects of exercise on cognitive function have been conducted in a wide range of age groups (from children to the elderly) and have attracted much attention. In particular, it has been shown that acute exercise improves executive function, one of the cognitive functions, but relatively few studies have examined the effects of aerobic exercise on executive function using treadmills or cycle ergometers. In studies conducted with children around 9 years of age, employing 20 minutes of aerobic exercise on a treadmill [3] [4] and a 20-minute cycle ergometer [5], the results showed that correct responses to the Flanker task, which assesses inhibitory function, one of the executive functions, increased and the authors reported that reaction times were shorter. In addition, in a study using a Stroop task to assess inhibitory function, it has been shown that 15 minutes [6] of aerobic exercise on a treadmill in children shortened the reaction time of the Stroop task and contributed to an increase in inhibitory functions. Furthermore, it has been reported that running or walking on a treadmill temporarily increases cognitive flexibility [7] and working memory capacity [8]. This is also true in the elderly, where a relationship between cognitive function and physical activity has been found with resistance exercise [9] [10]. Other studies have shown that moderate-to-high intensity exercise such as cycling [5] [11] increases executive function.

Although many of these studies have examined moderate-intensity aerobic exercise as the primary exercise task, some studies showing the relationship between exercise intensity and cognitive function have reported that low-intensity exercise promotes cognitive improvement [12] [13]. This indicates that even a

low-intensity exercise load may be effective in improving cognitive function. Even low- to moderate-intensity exercise may cause a subject to feel fatigued, depending on its content and duration. On the other hand, stretching exercises have been reported to have beneficial psychological effects, such as reducing stress reactions and improving mood [14] [15]. However, conventional studies have set up programs with implementation times of 20 to 30 minutes. Therefore, shorter stretching programs are needed in order to work more easily in one's free time. At this stage, there are still few studies that have clarified the effects of brief stretching exercises or gymnastics on cognitive function, and few studies have measured the autonomic nervous system activity during the performance of post-exercise tasks to verify their effects.

In this study, we examined the effects of a short 7-minute stretching gymnastics regime on autonomic nervous system activity and cognitive function. The cognitive function was evaluated in terms of the higher cognitive function, which is part of the executive function that controls inappropriate behavior (inhibitory function) and switching (cognitive flexibility) in order to achieve a goal.

2. Methods

2.1. Participants

There were 21 healthy participants in this study, 10 males and 11 females, between the ages of 18 and 30. The inclusion criteria we applied specified males and females over 18 years of age who were physically and mentally healthy. Of particular importance was the ability to perform physical exercise with the entire body. As exclusion criteria, we excluded participants from taking part in the study if they had an illness or were taking medication. All of the participants performed three tasks, 1) Stretch Well Gymnastics, 2) Stretch Band Gymnastics, and 3) Radio Gymnastics, on different days. The Stretch Well Gymnastics were 14 stretches designed based on the Core Balance Stretch [16] and consisted mainly of stretches for the neck, trapezius, mastoid, pectoralis major, shoulder deltoid, adductor and quad muscles. Stretch Band Gymnastics focused on nine areas: the trapezius, sternocleidomastoid, pectoralis major, rhomboids, psoas, quadriceps, adductor, gluteus maximus, and the hamstring, using a stretch band (nobitel Inc.). In the Radio Gymnastics task, the First (13 types) and Second Gymnastics (13 types) sessions were performed continuously. The First Gymnastics session included elements that balanced the muscles and joints of the entire body, while the Second Gymnastics session included elements that strengthened and toned the body and muscles. The Stretch Well Gymnastics and Radio Gymnastics tasks were performed in the standing position. In the Stretch Band Gymnastics task, upper body stretches were performed in the standing position and lower body stretches were performed in the seated position. The Medical Research Ethics Review Committee at the Kyoto University of Advanced Science approved the study protocol (No. 22M04). Verbal and written informed consent were obtained from each participant.

2.2. Procedures

All of the participants were asked to wear a Polar H10 heart rate sensor and rest in a chair for 3 minutes. Then, the cognitive tasks were performed, followed by the stretching exercises (Stretch Well Gymnastics, Stretch Band Gymnastics, Radio Gymnastics). The cognitive function was measured again after the stretching exercises. The heart rate was measured continuously from the beginning to the end of the experiment. The duration of the exercise was about 7 minutes for all of the sessions, based on the Radio Gymnastics (First Gymnastics and Second Gymnastics). All of the gymnastics were performed while watching a video. In order to exclude the effect of music, all exercises were performed with the sound turned off and only the video was employed.

2.3. Heart Rate and the Autonomic Nervous System Analysis

In this study, the effects of the stretching exercises on the autonomic nervous system activity were analyzed from electrocardiograms (ECG). The ECG data were acquired to clarify the changes using a Polar H10 heart rate sensor during each condition. The heart rates were measured at three points (Figure 1): HR-A (10 min during the cognitive tasks), HR-B (during the Stretch Well Gymnastics, the Stretch Band Gymnastics, and the Radio Gymnastics sessions), and HR-C (10 min during the second cognitive tasks). The mean values were used in the analysis. This data was transmitted via Bluetooth® to an iPhone app (Heart Rate Variability Logger) [17] [18]. The autonomic activity was analyzed using the Kubios HRV Version 3.5 (Kubios Oy) using the RR interval of the ECG. The heart rate variables analyzed were: the frequency domain measurements, including low-frequency power [LF (ms^2), 0.04 - 0.15 Hz], high-frequency power [HF (ms^2), 0.15 - 0.4 Hz], and LF/HF (the ratio of absolute LF power to HF power) [19]. The LF in the low-frequency power range obtained by frequency analysis of heart rate variability reflects both sympathetic and parasympathetic nervous system activity, while the HF in the high-frequency power is an index of parasympathetic nerve activity. Additionally, the LF/HF ratio is an index of the sympathetic nerve activity. The LF/HF ratio is frequently used as a simple index of sympathetic nervous activity (or an index to evaluate the balance between the sympathetic and parasympathetic nervous systems).

2.4. Cognitive Tasks

The executive function, one of the cognitive functions, is a higher-order cognitive function that controls (inhibitory control) or switches (cognitive flexibility) inappropriate behavior in order to achieve a goal [20], and it is considered to be

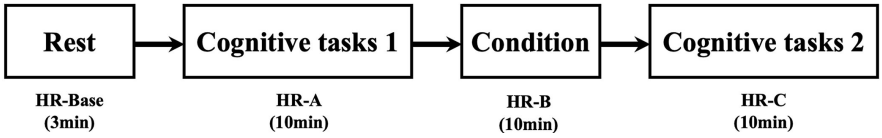

Figure 1. Experimental design in the present study.

one of the cognitive functions involved in sociality. In this study, we assessed executive function by having the participants perform 2 tasks; the Stroop task and the Number-Letter task. All programs for the cognitive tasks were created using E-Prime3 software for cognitive experiments and implemented on a Surface2 notebook, running Windows 8. The time required was about 10 minutes for all of the cognitive tasks.

2.4.1. Inhibitory Function—Stroop Task

The Stroop task is a matching test consisting of the following three sub-tasks, each of which uses four different color name words (blue, yellow, red, and green) written in hiragana and their corresponding four colors patches. The contents of each task and the usual implementation method are as follows. For each task, a fixation point was presented in the center of the screen for one second after the start of the task, and then the target stimulus was displayed for five seconds. The colors and letters of the choices were four types (blue, yellow, red, and green), the letters were hiragana, and the letters were painted the same color, so that they were the same in all tasks. The target stimuli in the congruent task consisted of four types of hiragana letters (blue, yellow, red, and green), and were presented in colors that matched the letters. The standard stimuli in the incongruent task were displayed in such a way that the colors applied to the four types of letters representing colors (blue, yellow, red, and green) were incongruent. For example, in the congruent task, when the word "red" was displayed in red in the center, the participants selected the same letter "red" from the choices of "blue" "yellow" "red" and "green" below. In the incongruent task, when the word "red" was displayed in green in the center, they chose "green" from the choices of "blue" "yellow" "red" and "green" below. Four sets of ten trials were performed for the matching task, and four sets of ten trials were performed for the incongruent task. The evaluation was based on the percentage of correct responses and the average reaction time (msec) in the incongruent task. The participants performed one trial of both congruent and incongruent tasks as practice before starting the task. In addition, the first trial of the incongruent task was excluded as a practice task in the analysis.

2.4.2. Switching—Number-Letter Task

The cognitive flexibility test [21] was a computerized task. Visual stimulus pairs consisting of a letter and a digit were presented. The letter was either a consonant (sampled randomly from the set G, K, M, and R) or a vowel (sampled randomly from the set A, E, I, and U). The digit was either even (sampled randomly from the set consisting of 2, 4, 6, and 8) or odd (sampled randomly from the set consisting 3, 5, 7, and 9) in the stimulus pairs. The letter and the digit, as well as the order of both in the stimulus pair, were randomly selected. Trials were administered in the form of a three-block design. The letter task (Block 1) was presented only in the upper block (4 trials), and the digit task (Block 2) was presented only in the lower block (4 trials). In the letter task, participants pressed a

left key when a consonant was presented and a right key when a vowel was presented in the stimulus pairs. In the digital task, participants pressed a left key when an even digit was presented and a right key when an odd digit was presented. All of the participants responded using the index fingers of their dominant hand. Additionally, the clockwise task (Block 3) was a presentation of the first stimulus pair in each block starting in the upper left box and the trial-to-trial presentation moved clockwise to the subsequent box (8 trials). When the letter and the digit were placed in the upper block, the participants answered using the number task method. On the other hand, when the letter and the digit were placed in the lower block, the participants answered using the letter task method. The evaluation was based on the percentage of correct responses and the average reaction time (msec) for trials 3, 5, 7, and 9, in which the pattern switched in each set of clockwise tasks. The subjects performed one trial each of the letter task, the digital task, and the clockwise task as practice before starting the real task. In addition, the first trial of the clockwise task was excluded as a practice task in the analysis.

2.5. Statistical Analysis

In this study, 21 participants were included in the analyses. Heart rate was calculated for each condition by averaging the values [HR-Base (3-minutes), HR-A (10-minutes), HR-B (7-minutes), and HR-C (10-minutes)].

HR-Base was measured to confirm that the exercise intensity was low. The %Intensity was calculated based on these heart rates using the Karvonen formula [%HRR Intensity = [(HR-B minus HR-Base)/(max HR minus HR-Base) × 100] [22]. As we could not measure the maximum heart rate (max HR) directly, it was roughly estimated using the traditional formula "220 minus age".

In order to clarify the changes that occurred during the execution of the cognitive tasks and exercises, the heart rate for each task was calculated by subtracting each time point (During = HR-B minus HR-A; After = HR-C minus HR-A).

The reaction time (Stroop and Number-Letter tasks) for each task was calculated by subtracting values obtained before each condition from those obtained after the condition (= "after" minus "before").

We conducted a two-way analysis of variance (ANOVA) with the HR and the autonomic nervous system (HF and LF/HF) as the dependent variables [within-subjects design: Session types (Stretch Well Gymnastics, Stretch Band Gymnastics, and Radio Gymnastics) × time point (During/After)]. Additionally, we conducted a one-way analysis of variance (ANOVA) with the difference in the reaction time (Stroop and Number-Letter tasks) for each session as dependent variables [within-subjects design: The session types were the Stretch Well Gymnastics, the Stretch Band Gymnastics, and the Radio Gymnastics)]. SPSS21.0J (IBM SPSS, Japan) was used for the data analysis. Regarding the results of the statistical analysis, a risk ratio of 5% or less was considered a significant difference.

3. Results

3.1. Exercise Intensity

The 21 healthy participants (mean age 20.2 ± 0.9 years) who took part in this study were 10 males (mean age 20.7 ± 0.9 years) and 11 females (mean age 19.9 ± 0.9 years). The exercise intensity was 16.9% ± 6.57% for the Stretch Well Gymnastics, 18.5% ± 9.76% for the Stretch Band Gymnastics, and 18.7% ± 11.14% for the Radio Gymnastics. The one-way ANOVA for the %HRR showed a significant effect for the session type [$F(2, 40) = 0.26$, *n.s.*, $\eta = 0.117$] .

3.2. HR and the Autonomic Nervous System

Figure 2 shows the differences in the HR (A), HF (B) and LF/HF (C) for each condition at each time point. The two-way ANOVA for the HR showed a significant effect for the time point [$F(1, 20) = 334.684$, $p < .001$, $\eta = 0.944$], but no significant effect of the session type [$F(2, 40) = 0.077$, *n.s.*, $\eta = 0.004$] or the session types × time point interaction [$F(2, 40) = 2.947$, *n.s.*, $\eta = 0.128$]. Multiple comparisons found that HR was significantly lower after each gymnastics session, compared with during the session.

Regarding the autonomic nervous system (HF and LF/HF) results, the two-way ANOVA for the HF showed a significant effect for the time point [$F(1, 20) = 132.752$, $p < 0.001$, $\eta = 0.869$], but no significant effect of the session type [$F(2, 40) = 2.142$, *n.s.*, $\eta = 0.097$] or the session type × time point interaction [$F(2, 40) = 1.125$, *n.s.*, $\eta = 0.053$]. Multiple comparisons found that HF was significantly higher after each gymnastic session, compared with during the session. Additionally, the two-way ANOVA for the LF/HF showed a significant effect of the time point [$F(1, 20) = 25.227$, $p < 0.001$, $\eta = 0.558$] and the effect of session type [$F(2, 40) = 3.68$, $p < 0.05$, $\eta = 0.156$] and session type × time point interaction [$F(2, 40) = 8.317$, $p < 0.001$, $\eta = 0.294$]. Multiple comparisons found that LFHF was significantly lower after each gymnastic session, compared with during the session. Moreover, the simple main effect found that the LFHF during gymnastics was significantly higher in the Stretch Well Gymnastics, compared with the Stretch Band Gymnastics and the Radio Gymnastics.

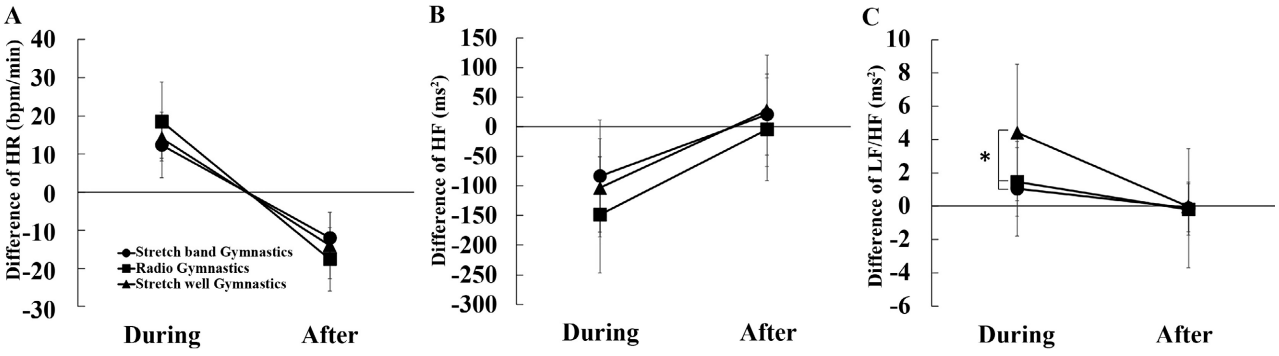

Figure 2. Differences in the HR (A), HF (B) and LF/HF (C) for each condition at each time point. *Note*. SD = Standard Deviation; η^2 = Effect Size. All p values smaller than $p = 0.05$ remain significant after Bonferroni correction.

3.3. Cognitive Tasks

Table 1 shows the differences in the reaction time for the conditions in the cognitive task. We carried out repeated-measures one-way ANOVAs on the differences between the accuracy rate (for all of the cognitive tasks) and the reaction time (for the Stroop and Number-Letter tasks) for each gymnastics session as dependent variables. The reaction time employed showed a significant effect related to the session type for the Stroop task [$F(2, 36) = 2.69$, $p < 0.10$, $\eta = 0.130$]. The results of the multiple comparisons in the Stroop task showed the highest values for the Radio Gymnastics sessions with marginally significantly lower scores for the Stretch Well Gymnastics sessions ($p < 0.10$). On the other hand, no significant difference was observed for the Number-Letter task [$F(2, 36) = 1.15$, *n.s.*, $\eta = 0.060$].

4. Discussion

In this study, we examined the effects of a brief 7-minute stretching gymnastics session on autonomic nervous system activity and cognitive function. First, %HRR lower than 30% is considered to be very light intensity exercise [23]. The %HRR of all of the gymnastics sessions (Stretch Well Gymnastics, Stretch Band Gymnastics and Radio Gymnastics) in this study was lower than 20%, which suggested that the exercise intensity was very light.

In regard to the autonomic nervous system, the results showed a significant increase in sympathetic nerve activity during the Stretch Well Gymnastics compared to the Radio Gymnastics and the Stretch Band Gymnastics. In addition, after the gymnastics sessions, all of the sympathetic nerve activity values decreased significantly, compared with during the gymnastics and then returned to the baseline. Parasympathetic nerve levels were significantly increased after the gymnastics sessions, compared with during the gymnastics, although there were no significant differences between any of the sessions. In addition, for all of the sessions, the parasympathetic nerve levels were higher than the baseline after the gymnastics. Conversely, the heart rate significantly increased during the gymnastics sessions, compared with after the sessions, although there were no significant

Table 1. Differences in the reaction time for the conditions in the cognitive task.

Task	Mean (SD) N = 19			F (df, error)
	Stretch well Gymnastics	Stretch band Gymnastics	Radio Gymnastics	Main Effect of Condition Types
Stroop	−85.593† (102.056)	−96.056 (117.828)	2.723† (72.576)	[$F(2, 36) = 2.69$, $p < 0.10$, $\eta^2 = 0.130$]
Number Letter	−125.400 (135.681)	−29.846 (74.845)	−4.771 (166.715)	[$F(2, 36) = 1.15$, *n.s*, $\eta^2 = 0.060$]

Note. SD = Standard Deviation; η^2 = Effect Size. All p values smaller than $p = 0.05$ remain significant after Bonferroni correction. $^{\dagger}p < 0.10$ vs Stretch well Gymnastics.

differences between any of the sessions. In addition, for all of the sessions, the values were lower than the baseline after the gymnastics. These results supported the effects of autonomic activity associated with conventional low or moderate-intensity exercise [12] [24]. However, in the present study, the sympathetic activity during the Stretch Well exercise sessions was characterized as more active than in the other exercise sessions, although relaxation was achieved in all cases after the stretching exercise sessions. The number of body movements recorded was 26 for the Radio Gymnastics and 14 for the Stretch Well Gymnastics, with Radio Gymnastics having more types of body movements. Therefore, the results indicated that, for the same amount of exercise time, the activation of sympathetic nerve activity may depend on the content of the gymnastics, not on the number of gymnastic types.

Regarding the cognitive function, there were no significant changes between the sessions in the reaction time of the cognitive flexibility. Cognitive flexibility has also been shown to be enhanced by 4 minutes of low-intensity coordination exercise, which also resulted in faster reaction times [13]. Thus, although there were no significant differences between the gymnastic exercise sessions, these results indicated that the stretching and exercises used in this study had an impact on cognitive flexibility. The inhibitory function has been shown to be significantly faster in reaction time to a Stroop task with low-intensity aerobic exercise [12]. The results of the present study indicate that the cognitive processing function was temporarily facilitated, similar to the results of previous studies, as responses were faster in all of the gymnastic exercise sessions. The most common studies on the effects of transient stretching gymnastics on cognitive function have been those that require 10 minutes or more of stretching gymnastics, but no studies have examined the effects of stretching gymnastics for as short a time as 7 minutes. Therefore, the fact that stretching gymnastics for less than 10 minutes has a positive effect on inhibitory function is a new finding. In particular, the reaction time tended to be faster for the Stretch Well Gymnastics exercise sessions, compared with the other exercise sessions. Thus, in light of the parasympathetic nerve activity increase after the aforementioned gymnastics, this indicates that Stretch Well Gymnastics is more effective than the other gymnastics in increasing the inhibitory function while relaxing. However, the extent to which the increase in sympathetic nerve activity during the brief Stretch Well Gymnastics and the extent to which the type and content of the exercises were involved in the improvement of cognitive function after stretching could not be clarified in this study, and further studies are required in the future. In particular, Stretch Well Gymnastics exercise randomly includes stretches that perform from slow to fast movements (three types) and stretches in which the body position is held for 10 seconds (five types). Bernardi *et al.* [25] reported that the tempo of the music played during this type of exercise affects the breathing rate, the heart rate, the blood pressure, and sympathetic nerve activity. Therefore, it is possible that a similar response may occur for changes in movement tempo. In

addition, five repetitions of 90 seconds of slow aerobics followed by 30 seconds of rest, although the exercise content and duration are different, will result in a faster reaction time for the Stroop task as well as for the 10-minute slow aerobics [26]. Thus, it can be inferred that changes in movement tempo can also help improve cognitive function. Therefore, it is desirable to conduct a more detailed examination of the effects of even shorter stretching gymnastics in terms of physiological indices, including autonomic nerve activity and cognitive function, in order to devise effective stretching gymnastics that can be easily implemented in certain situations in daily life.

In regard to the limitations of the present study, there was a lack of sufficient statistical substance due to the size of the limited population of young adults. Accordingly, future studies will be required to clarify the results we obtained in this study and especially, more detailed studies should be conducted in order to take additional confounding factors into consideration, such as enjoyment due to the content of the gymnastics, situations of need, and any habits for stretching or gymnastics and physical activity. Larger participant samples would also be beneficial, with expanded age ranges and occupations, including workers. Although the stretching gymnastics in this study mainly consisted of simple movements, it may be considered that the less flexible the body is in some types of gymnastics, the greater the psychological burden may be. In this study, we did not confirm the flexibility or the range of the body motion. Therefore, it is necessary to take these points into consideration while also collecting data on psychological and physiological responses to stretching gymnastics over time.

5. Conclusions

We examined the effects of stretch gymnastics on the autonomic nervous system activity and cognitive functions in young adults. The data obtained in the present study showed that the sympathetic activity during the Stretch Well Gymnastics was characterized as more active than in the Stretch Band Gymnastics and the Radio Gymnastics, although relaxation was achieved after all of the exercise sessions, and that cognitive processing function was temporarily facilitated. These results were similar to the results of previous studies, as the responses were faster in all of the exercise sessions.

In particular, the fact that participating in stretching gymnastics for less than 10 minutes has a positive effect on inhibitory function and cognitive flexibility is a new finding.

Acknowledgements

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Conflicts of Interest

The author hereby declares no potential conflicts of interest.

References

[1] Arai, Y., Saul, J.P., Albrecht, P., Hartley, L.H., Lilly, L.S., Cohen, R.J. and Colucci, W.S. (1989) Modulation of Cardiac Autonomic Activity during and Immediately after Exercise. *American Physiological Society*, **256**, H132-H141. https://doi.org/10.1152/ajpheart.1989.256.1.H132

[2] Niemela, H.T., Kiviniemi, M.A., Hautala, J.A., Salmi, A.J., Linnamo, V. and Tulppo, P.M. (2008) Recovery Pattern of Baroreflex Sensitivity after Exercise. *Medicine & Science in Sports & Exercised*, **40**, 864-870. https://doi.org/10.1249/MSS.0b013e3181666f08

[3] Hillman, C.H., Pontifex, M.B., Raine, L.B., Castelli, D.M., Hall, E.E. and Kramer, A.F. (2009) The Effect of Acute Treadmill Walking on Cognitive Control and Academic Achievement in Preadolescent Children. *Neuroscience*, **159**, 1044-1054. https://doi.org/10.1016/j.neuroscience.2009.01.057

[4] Drollette, E.S., Scudder, M.R., Raine, L.B., Moore, R.D., Saliba, B.J., Pontifex, M.B. and Hillman, C.H. (2014) Acute Exercise Facilitates Brain Function and Cognition in Children Who Need It Most: An ERP Study of Individual Differences in Inhibitory Control Capacity. *Developmental Cognitive Neuroscience*, **7**, 53-64. https://doi.org/10.1016/j.dcn.2013.11.001

[5] Chang, Y.K., Chen, F.T., Kuan, G., Wei, G.X., Chu, C.H., Yan, J., Chen, A.G. and Hung, T.M. (2019) Effects of Acute Exercise Duration on the Inhibition Aspect of Executive Function in Late Middle-Aged Adults. *Frontiers in Aging Neuroscience*, **11**, 227-236. https://doi.org/10.3389/fnagi.2019.00227

[6] Chu, C., Kramer, A.F., Song, T., Wu, C., Hung, T. and Chang, Y. (2017) Acute Exercise and Neurocognitive Development in Preadolescents and Young Adults: An ERP Study. *Neural Plasticity*, **7**, Article ID: 2631909. https://doi.org/10.1155/2017/2631909

[7] Bae, S. and Masaki, H. (2019) Effects of Acute Aerobic Exercise on Cognitive Flexibility Required during Task-Switching Paradigm. *Frontiers in Human Neuroscience*, **13**, 260. https://doi.org/10.3389/fnhum.2019.00260

[8] Schaefer, S., Lövdén, M., Wieckhorst, B. and Lindenberger, U. (2010) Cognitive Performance Is Improved While Walking: Differences in Cognitive-Sensorimotor Couplings between Children and Young Adults. *European Journal of Developmental Psychology*, **7**, 371-389. https://doi.org/10.1080/17405620802535666

[9] Weuve, J., Kang, J.H. and Manson, J.E. (2004) Physical Activity, Including Walking, and Cognitive Function in Older Women. *JAMA*, **292**, 1454-1461. https://doi.org/10.1001/jama.292.12.1454

[10] Johnson, L., Addamo, P.K., Selva, R.I., Borkoles, E., Wyckelsma, V., Cyarto, E. and Polman, R.C. (2016) An Acute Bout of Exercise Improves the Cognitive Performance of Older Adults. *Journal of Aging and Physical Activity*, **24**, 591-598. https://doi.org/10.1123/japa.2015-0097

[11] Hyodo, K., Dan, I., Suwabe, K., Kyutoku, Y., Yamada, Y., Akahori, M., Byun, K., Kato, M. and Soya, H. (2012) Acute Moderate Exercise Enhances Compensatory Brain Activation in Older Adults. *Neurobiology of Aging*, **33**, 2621-2632. https://doi.org/10.1016/j.neurobiolaging.2011.12.022

[12] Byun, K., Hyodo, K., Suwabe, K., Ochi, G., Sakairi, Y., Kato, M., Dan, I. and Soya, H. (2014) Positive Effect of Acute Mild Exercise on executive Function via Arousal-Related Prefrontal Activations: An fNIRS Study. *Neuroimage*, **98**, 336-345. https://doi.org/10.1016/j.neuroimage.2014.04.067

[13] Mitsuishi, H. and Ogi, T. (2022) The Effects of Interactive Fitness Video Games on

Stress and Cognitive Function. *Journal of Digital Life*, **2**, Article No. 6.

[14] Eda, N., Ito, H. and Akama, T. (2020) Beneficial Effects of Yoga Stretching on Salivary Stress Hormones and Parasympathetic Nerve Activity. *Journal of Sports Science and Medicine*, **19**, 695-702.

[15] Sudo, M. and Ando, S. (2020) Effects of Acute Stretching on Cognitive Function and Mood States of Physically Inactive Young Adults. *Perceptual and Motor Skills*, **127**, 142-153. https://doi.org/10.1177/0031512519888304

[16] Naraoka, Y., Katagiri, M. and Shirasawa, T. (2017) Effectiveness of a 12-Week Program of Active and Passive Stretching in Improving Low Back and Neck Pain in Japanese Sedentary Men. *Health*, **9**, 493-505. https://doi.org/10.4236/health.2017.93035

[17] Altini, M. and Amft, O. (2016) HRV4Training: Large-Scale Longitudinal Training Load Analysis in Unconstrained Free-Living Settings Using a Smartphone Application. *Annual International Conference of the IEEE Engineering in Medicine and Biology*, Orlando, 16-20 August 2016, 2610-2613. https://doi.org/10.1109/EMBC.2016.7591265

[18] Yoghourdjian, V., Yang, Y., Dwyer, T., Lawrence, L., Wybrow, M. and Marriott, K. (2020) Scalability of Network Visualisation from a Cognitive Load Perspective. *IEEE Transactions on Visualization and Computer Graphics*, **27**, 1677-1687. https://doi.org/10.1109/TVCG.2020.3030459

[19] Malik, M. (1996) Heart Rate Variability: Standards of Measurement, Physiological Interpretation, and Clinical Use. Task Force of the European Society of Cardiology and the North American Society for Pacing and Electrophysiology. *Annals of Noninvasive Electrocardiolgy*, **1**, 151-181. https://doi.org/10.1111/j.1542-474X.1996.tb00275.x

[20] Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A. and Wager, T.D. (2000) The Unity and Diversity of Executive Functions and Their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis. *Cognitive Psychology*, **41**, 49-100. https://doi.org/10.1006/cogp.1999.0734

[21] Rogers, R.D. and Monsell, S. (1995) Costs of a Predictible Switch between Simple Cognitive Tasks. *Journal of Experimental Psychology*: *General*, **124**, 207-231. https://doi.org/10.1037/0096-3445.124.2.207

[22] American College of Sports Medicine, Brubaker, P.H., Otto, R.M. and Armstrong, L.E. (2006) ACSM's Guidelines for Exercise Testing & Prescription. 7th Edition, Lippincott, Williams & Wilkins, Baltimore.

[23] Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., Nieman, D.C. and Swain, D.P. (2011) Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise*, **43**, 1334-1359. https://doi.org/10.1249/MSS.0b013e318213fefb

[24] Chang, Y.K., Chi, L., Etnier, J.L., Wang, C.C., Chu, C.H. and Zhou, C. (2014) Effect of Acute Aerobic Exercise on Cognitive Performance: Role of Cardiovascular Fitness. *Psychology of Sport and Exercise*, **15**, 464-470. https://doi.org/10.1016/j.psychsport.2014.04.007

[25] Bernardi, L., Porta, C. and Sleight, P. (2006) Cardiovascular, Cerebrovascular, and Respiratory Changes Induced by Different Types of Music in Musicians and Non-Musicians: The Importance of Silence. *Heart*, **92**, 445-452. https://doi.org/10.1136/hrt.2005.064600

[26] Hyodo, K., Suwabe, K., Yamaguchi, D., Soya, H. and Arao, T. (2021) Comparison between the Effects of Continuous and Intermittent Light-Intensity Aerobic Dance Exercise on Mood and Executive Function in Older Adults. *Frontiers in Aging Neuroscience*, **6**, Article ID: 723243. https://doi.org/10.3389/fnagi.2021.723243