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RESEARCH

The Effect of Acute Aerobic Exercise with Music on Executive Function: The Major Role of Tempo Matching

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Objective: The beneficial effects of music on executive function during exercise have been widely reported. However, little is known about the cause of the more beneficial effects. This study aims to investigate whether tempo matching is one of the reasons for the beneficial effects.
Methods: 90 young adults (aged 21.54 ± 2.26 years) were randomly assigned to three groups: the slower mismatched exercise heart rate group (SMG, with music at 60–65 bpm), the matched exercise heart rate group (MG, with music at 120–140 bpm), and the faster mismatched exercise heart rate group (FMG, with music at 155–165 bpm). Then, they completed a 20-minute bout of moderate-intensity (60%–70% of maximum heart rate) aerobic exercise respectively, with corresponding musical contains. The exercise states (heart rate and rating of perceived exertion) were measured throughout experimental procedures, and emotional states, as well as the executive function (inhibitory control, cognitive flexibility, and working memory), were assessed pre- and post-exercise.
Results: Greater exercise states and more positive emotional states were noted in MG. Additionally, the MG gained increased executive function performance (i.e., inhibitory control and working memory).
Conclusions: Tempo matching is an important element for the beneficial effects of exercise with music on executive function. People could choose music in tempo which matches heart rate during exercise to get better effects both physically and psychologically.

Keywords: Acute aerobic exercise; music tempo; matching; executive function

Introduction

A growing number of people get used to listening to music while participating in exercise (e.g., running and cycling). The beneficial effects of exercise with music on exercise states (Loizou and Karageorghis, 2015, Stork et al., 2015) and psychology (Frith and Loprinzi, 2018, Hars et al., 2014) have been widely established. Music is effective in exercise states, i.e., music can decrease the rating of perceived exertion (RPE) and subjective fatigue (Bigliassi et al., 2017, Hutchinson et al., 2018) during exercise. Additionally, exercise with music condition has positive effects on emotional regulation and modification of affective arousal (Hutchinson et al., 2018). This is because exercise with music is described as a cognitive separation strategy that shifts attention away from subjective experiences of discomfort or fatigue (Altenmüller and Schlaug, 2013). Moreover, synchronous music has proved to enhance the release of endorphin, as well as inhibits the release of corticotrophin, resulting in a positive emotional experience (Crust, 2004, Esch et al., 2004).

Besides, an increasing number of studies have focused on cognitive function. Cognitive function refers to a basic stage of people's mental activity process, cognitive function generally includes attention, memory and so on (Diamond et al., 2004). Music with exercise has more beneficial effects on improved cognitive function than no music condition (Emery et al., 2003). Firth *et al.* (Frith and Loprinzi, 2018) reported that listening to music during exercise significantly enhances cognitive creativity in young adults. Researchers found similar positive effects on cognitive function (i.e., memory function and verbal fluency) than exercise without music among the children (Moreno et al., 2011), the older adults (Shimizu et al., 2018), and the Alzheimer's disease (Johnson et al., 1998). Additionally, the exercise with music pattern displayed positive effects on higher-order cognitive function (i.e., executive function). The executive function contained a series of high-order cognitive processes, including inhibitory control, cognitive flexibility, and working memory (WM) (Diamond, 2013, Miyake et al., 2000). Executive function (also called executive control or cognitive control) refers to a family of top-down mental processes needed when you have to concentrate, when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible (Miller and Cohen, 2001). In a previous work of our laboratory, 120 college students were recruited and randomly assigned to the four groups: 20 min moderate-intensity (60–70% HRmax) aerobic exercise group, the music group (120–140 bpm), the exercise with the music group, and the control group. Then we found that the exercise with the music group had gained significant improvement in executive function (mainly inhibitory control and WM) than other groups during and immediately after exercise. These results indicated that music with aerobic exercise can bring more executive function benefits than exercise without music among young adults (Rui et al., 2020).

However, there is no clear explanation that the improved cognitive function in the context. A plausible explanation for the beneficial effects is that matching music to the tempo of the exercise. The resonance between these might beneficial for the cognition effects. Rhythmical elements of music alternate pathways by helping to better organize cortical brain transmissions (Rauscher et al., 1993) and contribute to neurophysiological changes linked with activation of the central nervous system (Dustman et al., 1990), and evoke the oscillation period certainly (Aoun et al., 2005). Listening to music also improves the activation of the network in the dorsal prefrontal cortex (Sesso and Sicca, 2020). Moreover, music can increase dopaminergic neurotransmission in subcortical structures (Akiyama and Sutoo, 2013). Meanwhile, the positive effects of exercise on executive function were now well established. Chen et al. reported that the college students had the better performance in the Flanker task, the 2-back task and the More-odd shifting task after acute aerobic exercise (Chen et al., 2011). It means that acute aerobic exercise has significant effects on college students' executive function. Chang *et al.* found that acute exercise improves performance on the Stroop task in middle-aged adults (Chang and Etnier, 2009), meaning better inhibitory control. A meta-analysis illustrated that exercise increases cerebral oxygenation in the prefrontal cortex during exercise (Rooks et al., 2010). Based on the evidence, it is reasonable that exercise with music could bring more beneficial effects on executive function.

Tempo, measured in bpm, is a major determinant of one's aesthetic and psychophysical response to a piece of music (Bishop et al., 2009), and it is the musical quality that is easiest to manipulate (Edworthy and Waring, 2006). Meanwhile, HR is also measured in bpm in the study of exercise and sports-related fields (Camm et al., 1996). The tempo of music matches that of HR during exercise might generate resonant frequency in the brain and influence processes in the autonomic nervous system involving breathing, attention, and cognitive function (Altenmüller and Schlaug, 2013). Previous studies illustrated that listening to music at 130–150 bpm during endurance exercise with the same bpm had more beneficial effects on HR and RPE (Patania et al., 2020).

This study aims to investigate whether the tempo matching plays a major role in the beneficial effects of aerobic exercise with music on executive function. In the above-mentioned experiments, some music has lyrics while others not. The lyrics in music materials possibly modulate the activity of the motor system by mirror neuron system (Buccino et al., 2005, Sesso and Sicca, 2020). Considering that tempo is an important variable in our experiment. We use music materials without lyrics, in order to eliminate the impression of the lyrics on the experimental results. Moreover, based on the benefits in exercise states and relevant neural mechanism, it is reasonable that combining exercise HR with matched music tempo enhances executive function more than mismatched music conditions. We hypothesize that young adults participating in exercise HR with matched tempo music would exhibit better executive function performance than those with exercise under mismatched music conditions.

Materials and methods

Participants

The target sample in this study was a minimum of 86 participants, as determined by G*power 3.1 (effect size = 0.25, α level = 0.05, power value = 0.8). Then 90 (45 females) eligible participants were recruited by posters from the local university and met the inclusion criteria: (1) age between 18 to 25 years old, (2) normal hearing, (3) normal color vision, (4) right-hand dominance, (5) no history of neurological diseases, and (6) no physical disability or other condition potentially influencing the exercise states of the participants. The demographic characteristics of the enrolled participants see **Table 1**. This study is following the Declaration

Table 1: Participants' demographic characteristics (M ± SD).

Variables	SMG	MG	FMG	F/χ^2
Number (females)	30 (15)	30 (14)	30 (16)	0.875
Age (yrs)	21.03 ± 2.37	22.06 ± 2.23	21.53 ± 2.18	0.069
BMI (kg/m^2)	21.52 ± 4.01	21.36 ± 2.99	21.23 ± 2.46	0.589
VO_{2max} (ml/kg/min)	44.94 ± 12.75	40.30 ± 13.27	43.30 ± 13.78	0.316
IPAQ (100METs/wk)	51.34 ± 25.32	52.49 ± 29.90	54.49 ± 27.53	0.642
Resting HR (bpm)	68.75 ± 4.94	68.30 ± 6.55	68.00 ± 4.10	0.934

Note: SMG, slower mismatched group; MG, matched group; FMG, faster mismatched group; BMI, Body Mass Index; VO2max, Maximal Oxygen Consumption; IPAQ, International Physical Activity Questionnaires; METs, Metabolic Equivalents. There were no significant differences between the three groups in demographic characteristics.

of Helsinki and was approved by the Ethics Committee of Ningbo University. All participants obtained written informed consent before this study. Each participant received 50 RMB after laboratory visits.

Music materials

To avoid the influence of music styles and lyrics on the experiment (Hutchinson et al., 2018, Patania et al., 2020), we chose pop music without lyrics and with three types of tempo: music at 60–65 bpm (low tempo), music at 120–140 bpm (moderate tempo), and music at 155–165 bpm (high tempo). Each song has been on the iTunes Hot 100 Chart for at least six months. In the pre-experimental phase, all participants assessed the characteristics of all music materials: preference (not at all to very much) and familiarity (not at all to very much) via 9-point Likert Scales, and arousal (very calm to very excited) as well as valence (very negative to very positive) via 5-point Likert Scales (Larsen et al., 2009). The volume of the music is 55 decibels. There were no significant differences between the three types of music in preference, familiarity, arousal, and valence. Finally, a total of 18 music materials (6 in each category) were selected in this study.

Rating of perceived exertion assessment

The RPE scale is a 15-point category-ratio scale ranging from 6 (very relaxed) to 20 (maximum exertion). The higher the RPE score, the higher the rating of perceived exertion during the experiment. The RPE scale has high temporal stability ($r > 0.83$) and intra-test ($r = 0.93$) reliability and is closely related to physiological indicators including heart rate (Borg and Kaijser, 2006, Borg, 1982).

Arousal status assessment

Arousal was defined as how aroused, excited, or awake they felt during exercise (Lang et al., 1993). The Felt Arousal Scale (FAS) is used to measure arousal status by six points, a single-item measure with anchors from 1 (low arousal) to 6 (high arousal) (Svebak and Murgatroyd, 1985).

Emotional states assessment

The Chinese Mood Adjective Check List (CMACL) was employed to measure participants' immediate emotional states (Jie and Ming-yi, 2005). There are four dimensions in the CAMAL: Fidget (F), Happy and Excited (HE), Pain and Sad (PS), Angry and Hate (AH). Each dimension with the statements from 1 (not at all) to 5 (very much).

Executive function assessment

The three subfunctions of executive function including inhibitory control, cognitive flexibility, and WM (Diamond, 2013) were assessed via a classical Stroop task, a More-odd shifting task, and a classical *n*-back task, respectively.

The Stroop task is a widely used measure of inhibitory control of executive function (Stroop, 1992, Sibley et al., 2006, Brush et al., 2016). Participants were presented at a visual of 5.1° × 5.4° with the names of colors printed in the different ink colors (e.g., the RED in Chinese printed in yellow ink; incongruent condition) or the same ink color (e.g., the RED in Chinese printed in red ink; congruent condition). Each stimulus word (i.e., red, yellow, green, and blue) was randomly presented in equal proportions on a gray background for 1500 ms. Participants were asked to respond as accurately and quickly as possible to the color of the ink with a button press on the keyboard (D, F, J, and K means red, yellow, green, and blue respectively), rather than the meaning of the word. The Stroop task consisted of two blocks of 96 trials (containing 48 congruent conditions and 48 incongruent conditions). Reaction time (RT, milliseconds) and accuracy (ACC, percent) were recorded. Accordingly, the interference score = incongruent Stroop RT minus congruent Stroop RT, and the interference ACC = congruent Stroop ACC minus incongruent Stroop ACC (Brush et al., 2016).

The cognitive flexibility (also called set-shifting) of executive function was measured by a More-odd shifting task (Salthouse et al., 2003) including three parts. In part A, participants were asked to assess whether the black number 1–9 (except 5) is bigger or smaller than 5, presented randomly for 2000 ms at a visual of 4.1° × 2.9°, with 5 in button press (F, D means greater and less respectively). Part A consisted of two blocks of 32 trials (including 16 trials less than 5 and 16 trials greater than 5). In part B, participants were asked to judge whether the green numbers from 1–9 (except 5), presented randomly for 2000 ms, were odd or even with button press (J, K means odd and even respectively). Part B consisted of two blocks of 32 trials (including 16 trials odd and 16 trials even). In part C, the numbers 1–9 (except 5) were randomly presented for 2000 ms. The participants were asked to assess whether the number 1–9 (except 5) is bigger or smaller than 5 if the color is black (F, D means greater and less respectively); to judge whether the number was odd or even if the color is green with button press (J, K means odd and even respectively). Part C consisted of two blocks of 64 trials (including 32 black number trials and 32 green number trials). Participants were required as accurately and quickly as possible. RT and ACC were recorded independent measures. Therefore, the shifting score = Part-C RT minus (Part-A RT plus Part-B RT)/2, and shifting ACC = (Part-A ACC plus Part-B ACC)/2 minus Part-C ACC.

The participants' WM was assessed with the n-back task (Smith et al., 1998) (1-back and 2-back tasks orderly). In the 1-back task, participants were presented at a visual of 4.3° × 3.6° with a continuous sequence of letters (A, H, J, G, P, and T) and were required to judge whether each letter matched the letter presented one letter back in the sequence. Then, in the 2-back task, the participants had to detect whether the letter presented on the screen matched the corresponding stimulus presented two trials back in a range of letters. Each letter was presented for 500 ms and separated by a 2000 ms delay. Participants responded as accurately and quickly as possible with button press (F, J means matched and mismatched respectively). There were two blocks of 48 trials in the 1-back task and 2-back task severally. RT and ACC were recorded independent measures. The n-back task can also indicate updating ability. Therefore, the updating score = 2-back RT minus 1-back RT, and the updating ACC = 1-back ACC minus 2-back ACC.

Procedures

The study consisted of two laboratory visits. Participants were asked not to do vigorous exercise, not to ingest caffeine as well as alcohol 24 hours before each visit, and to get normal amounts of sleep.

On the first visit, each participant was instructed to provide background information including Body Mass Index (BMI), resting HR via Polar sports tester (Polar-A300, Polar, Inc., Finland), and physical activity status via International Physical Activity Questionnaires (IPAQ). Besides, participants assessed characteristics (including preference, familiarity, arousal, and valence) of all music materials.

On the second visit, the participants were randomly divided into the three exercise groups with different tempo music: slower mismatched group (SMG), the music tempo was slower than exercise HR; matched group (MG), the music tempo matched exercise HR; and faster mismatched group (FMG), the music tempo was faster than the exercise HR. The aerobic exercise involved a 5-min warm-up, a 20-min main exercise period performed using a bicycle ergometer at 50–60 rpm, and a 5-min cool-down. During the main exercise, the participants were instructed to cycle while keeping their HR at the range of 60–70% of their maximum HR (206.9–0.67 × age) (Gellish et al., 2007), with listening to music in an earphone (Oppo-mh133). HR and RPE were recorded every 2 min throughout the experimental procedures.

Arousal status was assessed pre-exercise, during exercise, immediately after exercise, and 40 min follow up. The emotional states were assessed pre-exercise, immediately after exercise, and 40 min follow up. The executive function assessment was completed pre-exercise and immediately after exercise. The whole experiment took about 2 hours.

Statistical analysis

One-way analysis of variance (ANOVA) and Chi-square tests were employed to analyze for background data differences between the three groups. The scores of arousal, emotion, and executive function could be obtained by subtracting the scores of pre-exercise from those of each time point, which was called Δ respectively. Averaged HR during exercise was analyzed using one-way ANOVA, and HR was analyzed using 3 (group: SMG, MG, and FMG) × 3 (time point: pre-exercise, during exercise, and immediately after exercise) repeated measures (RM) ANOVA. The scores of RPE and ΔArousal status were analyzed using 3 (group) × 3 (time point:

during exercise, immediately after exercise, and follow-up) RM ANOVA, respectively. For the emotional states, the scores of ΔHE, ΔPS, ΔF, and ΔAH were analyzed using 3 (group) × 2 (time point: immediately after exercise and follow-up) RM ANOVA, respectively. For the executive function tasks, the changes of the interference scores (ΔInterference scores), the interference ACC (ΔInterference ACC), the shifting scores (ΔShifting scores), the shifting ACC (ΔShifting ACC), the updating scores (ΔUpdating scores), as well as the updating ACC (ΔUpdating ACC) were analyzed separately using one-way ANOVA. Where main effects were detected, post-hoc tests with Bonferroni adjustments were used to determine where significant differences existed. And the Greenhouse-Geisser correction was applied. The effect size of significant main and interaction effects i.e., alpha at 0.05 before adjustment was reported as η_p^2.

Results

Exercise states

The averaged HR during exercise analysis showed no significant differences ($p > 0.05$). The HR analysis showed significant main effects by time point [F (2, 168) = 7356.26, $p < 0.001$, $\eta_p^2 = 0.99$]. The post-hoc test revealed that HR during exercise higher than the HR pre- and post-exercise ($p < 0.001$). Neither the main effects of the group nor interaction effects were observed ($ps > 0.05$).

The scores of RPE analysis showed significant main effects by group [F (2, 168) = 748.01, $p < 0.001$, $\eta_p^2 = 0.99$] and time point [F (2, 84) = 15.53, $p < 0.001$, $\eta_p^2 = 0.27$] and an interaction between group and time point [F (4, 168) = 3.25, $p < 0.05$, $\eta_p^2 = 0.07$]. Follow-up comparisons showed that the RPE scores of SMG were higher than that of the other two groups during exercise and post-exercise ($ps < 0.05$) (see **Figure 1**).

Arousal and emotional states

The scores of ΔArousal analysis showed significant main effects by group [F (2, 84) = 3.97, $p < 0.05$, $\eta_p^2 = 0.09$] and time point [F (2, 186) = 141.54, $p < 0.001$, $\eta_p^2 = 0.63$] and an interaction between group and time point [F (4, 168) = 7.80, $p < 0.001$, $\eta_p^2 = 0.16$]. Follow-up comparisons showed that the ΔArousal scores of SMG was less than that of the other two groups during exercise and immediately after exercise ($ps < 0.05$) (see **Figure 2**).

The analysis of ΔHE scores revealed that significant main effects by group [F (2, 84) = 7.15, $p < 0.001$, $\eta_p^2 = 0.16$] and time point [F (1, 84) = 31.82, $p < 0.001$, $\eta_p^2 = 0.28$] and an interaction between group and time point [F (2, 84) = 4.90, $p < 0.05$, $\eta_p^2 = 0.11$]. Follow-up comparisons showed that the ΔHE scores of MG were higher than that of the FMG ($p < 0.05$) which was higher than that of the SMG ($p < 0.05$) immediately after exercise. Additionally, 40 min after exercise, the ΔHE scores of MG was higher than that of the SMG ($p < 0.05$) (see **Table 2** and **Figure 3a**).

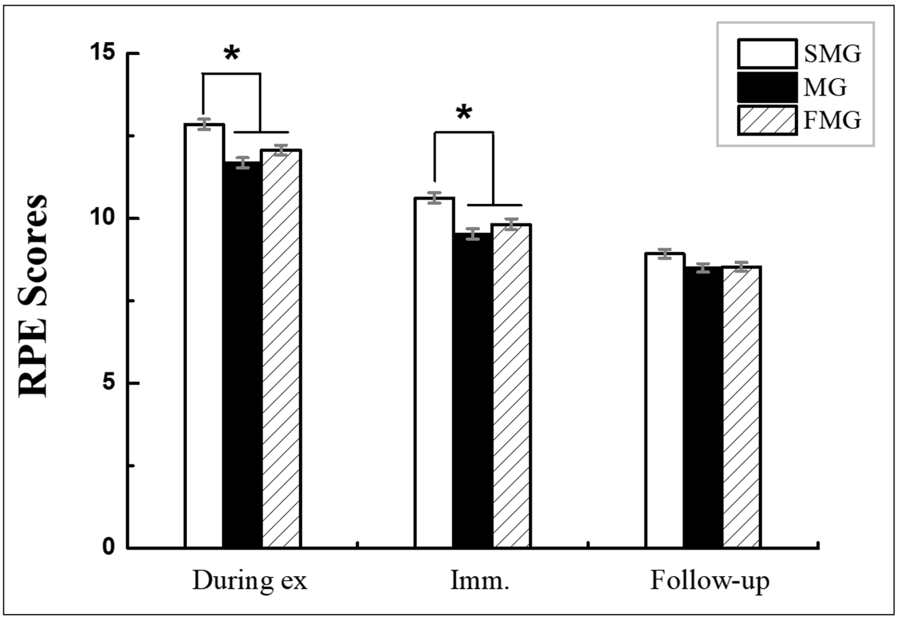

Figure 1: The RPE scores of groups at different time points.

Note: During ex, during exercise; Imm., immediately after exercise; Follow-up, 40 min follow-up The RPE scores of SMG were significantly higher than that of the other two groups during exercise and immediately after exercise. * $p < 0.05$.

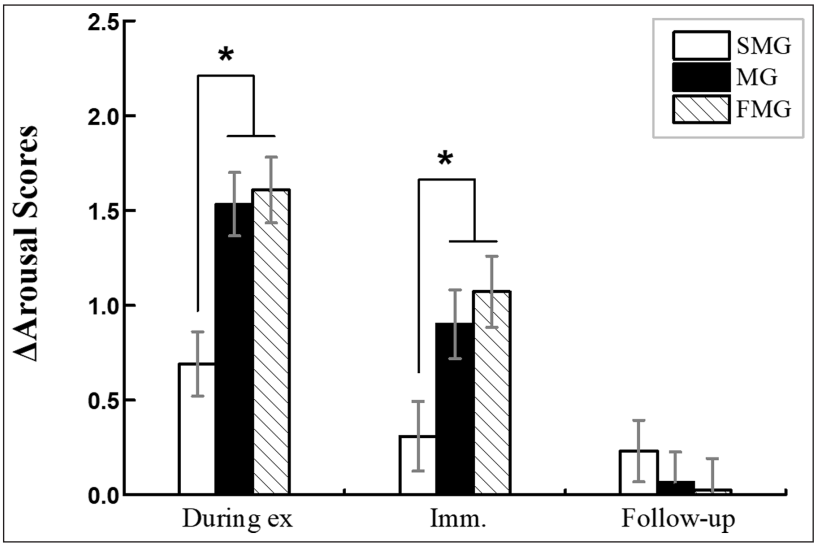

Figure 2: The ΔArousal scores of groups at different time points.
Note: During ex, during exercise; Imm., immediately after exercise; Follow-up, 40 min follow-up. The ΔArousal scores of SMG were significantly lower than that of the other two groups during exercise and immediately after exercise. * $p < 0.05$.

Table 2: Emotional states scores of groups at different time points (M ± SD).

	SMG	MG	FMG
Happy and Excited			
Pre-ex	15.48 ± 4.32	17.16 ± 4.55	14.63 ± 3.82
Imm.	17.03 ± 4.27	22.77 ± 2.99	18.17 ± 3.25
Follow-up	16.38 ± 4.09	20.53 ± 4.24	17.13 ± 3.34
ΔImm.	1.55 ± 2.49*	5.61 ± 4.52	3.54 ± 1.75*
ΔFollow-up	0.90 ± 3.11*	3.37 ± 5.86	2.50 ± 1.62
Angry and Hate			
Pre-ex	9.55 ± 2.16	10.42 ± 2.58	9.03 ± 0.18
Imm.	9.27 ± 1.30	9.22 ± 1.12	8.77 ± 0.13
Follow-up	9.07 ± 0.54	9.19 ± 1.12	8.67 ± 0.19
ΔImm.	–0.28 ± 1.03	–1.20 ± 2.63	–0.26 ± 0.14*
ΔFollow-up	–0.48 ± 1.91	–1.23 ± 2.55	–0.36 ± 0.15*
Pain and Sad			
Pre-ex	7.90 ± 1.90	8.77 ± 2.31	7.91 ± 1.23
Imm.	7.28 ± 0.67	7.30 ± 0.88	7.02 ± 1.21
Follow-up	7.19 ± 0.79	7.40 ± 1.15	7.05 ± 0.18
ΔImm.	–0.62 ± 1.51	–1.47 ± 1.96	–0.89 ± 1.23
ΔFollow-up	–0.71 ± 1.40	–1.37 ± 2.26	–0.86 ± 1.16
Fidget			
Pre-ex	12.32 ± 3.23	12.61 ± 2.31	11.44 ± 2.68
Imm.	10.01 ± 2.02	9.51 ± 0.88	9.19 ± 0.47
Follow-up	9.77 ± 1.42	9.41 ± 1.15	9.50 ± 1.30
ΔImm.	–2.31 ± 3.23	–3.10 ± 1.96	–2.25 ± 2.71
ΔFollow-up	–2.55 ± 3.26	–3.20 ± 2.26	–1.94 ± 2.71

Note: Imm., immediately after exercise. The ΔImm. means the scores immediately after exercise minus the scores pre-ex and ΔFollow-up means the scores 40 min after exercise minus the scores pre-ex. * $p < 0.05$.

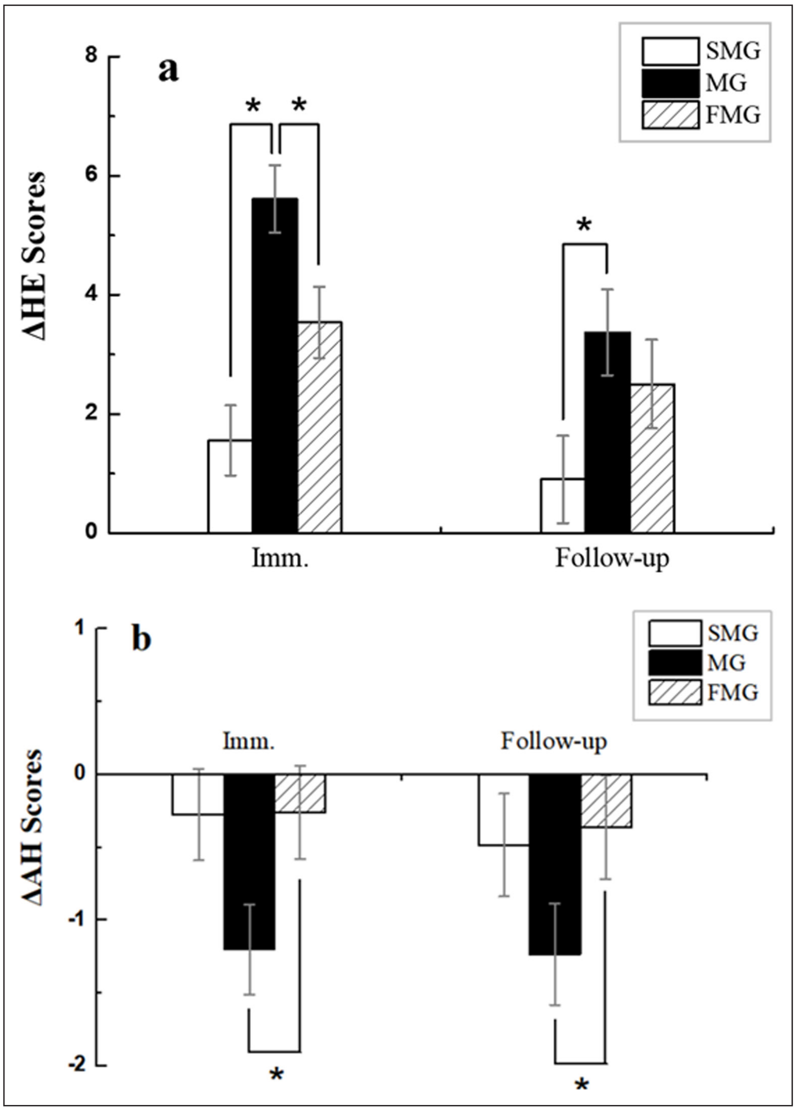

Figure 3: The emotional states of groups at different time points.

Note: Imm., immediately after exercise; Follow-up, 40 min follow-up. **(a)** There were significant differences in ΔHE scores between the MG and the other two groups at different time points. **(b)** There were significant differences of ΔAH between the MG and the FMG at different time points. * $p < 0.05$.

The analysis of ΔAH scores revealed that significant main effects by the group [F (2, 84) = 3.51, $p < 0.05$, $\eta_p^2 = 0.08$]. The post-hoc test revealed that the ΔAH scores of MG less than that of the FMG ($p < 0.05$). Neither the main effects of time point nor interaction effects were observed (*ps* > 0.05) (see **Table 2** and **Figure 3b**).

Regarding the ΔPS scores and the ΔF scores, neither main effects nor interaction effects were observed (*ps* > 0.05).

Executive function

The ΔInterference scores analysis revealed significant main effects by the group [F (2, 84) = 9.19, $p < 0.01$, $\eta_p^2 = 0.18$]. The post-hoc tests showed that the ΔInterference scores of MG were less than that of the other two groups (*ps* < 0.001). No significant effects were showed in the changes in the interference ACC (ΔInterference ACC) (*ps* > 0.05) (see **Table 3** and **Figure 4a**).

The analysis of the ΔShifting scores and the ΔShifting ACC revealed no significant main effects of groups (*ps* > 0.05).

Regarding the ΔUpdating scores, the main effects of the group [F (2, 84) = 8.21, $p < 0.01$, $\eta_p^2 = 0.16$] was revealed in ΔUpdating scores. The post-hoc test showed that the ΔUpdating scores of MG were less than that of the other two groups (*ps* < 0.001). No significant effects were observed in ΔUpdating ACC (*ps* > 0.05) (see **Table 3** and **Figure 4b**).

Table 3: Executive function performance of groups in different experimental tasks (M ± SD).

	SMG	MG	FMG
Interference scores			
Pre-ex	114.85 ± 10.54	115.78 ± 7.56	145.74 ± 7.64
Imm.	102.11 ± 9.43	63.03 ± 7.27	131.94 ± 7.71
ΔInterference scores	−12.74 ± 6.91*	−52.75 ± 6.49	−13.80 ± 7.45*
Interference accuracy			
Pre-ex	3.18 ± 4.46	3.23 ± 5.59	3.17 ± 4.17
Imm.	4.23 ± 4.62	4.90 ± 0.09	3.32 ± 4.56
ΔInterference accuracy	1.05 ± 0.11	1.67 ± 4.66	0.15 ± 0.11
Shifting scores			
Pre-ex	249.39 ± 178.83	179.08 ± 194.25	211.74 ± 158.56
Imm.	199.23 ± 165.54	121.41 ± 140.94	189.41 ± 148.43
ΔShifting scores	−50.16 ± 166.33	−57.67 ± 108.41	−22/33 ± 148.76
Shifting accuracy			
Pre-ex	7.74 ± 11.13	7.85 ± 10.05	7.42 ± 10.18
Imm.	8.35 ± 11.76	8.40 ± 6.07	8.13 ± 9.27
ΔShifting accuracy	0.61 ± 10.02	0.55 ± 7.98	0.71 ± 9.03
Updating scores			
Pre-ex	165.14 ± 116.35	174.96 ± 88.50	195.14 ± 110.62
Imm.	133.95 ± 108.43	98.29 ± 85.13	160.44 ± 97.86
ΔUpdating scores	−31.198 ± 64.22**	−76.67 ± 56.03	−34.7 ± 58.09**
Updating accuracy			
Pre-ex	5.34 ± 8.78	5.70 ± 8.54	5.16 ± 7.65
Imm.	6.59 ± 7.56	6.67 ± 5.89	6.27 ± 7.34
ΔUpdating scores	1.25 ± 10.34	0.97 ± 13.81	1.11 ± 11.89

Note: Imm., immediately after exercise. The Δ means scores and accuracy subtracting those of the pre-ex from those of the immediately after exercise. * $p < 0.05$. ** $p < 0.01$.

Discussion

This study aimed to examine whether tempo matching played an important role in the beneficial effects of aerobic exercise with music on executive function among young adults. It is well known that forms of exercise, such as cycling and running, generate HR tempo and movement tempo. For example, the cycle can be divided into two movements: going down with the foot and going up with the foot. However, HR tempo is more closely linked to brain function. The rhythmic pumping of the heart allows the brain to be regularly affected by the neurotransmitters during exercise. Therefore, we focus on matching the music tempo to HR rather than the movement tempo. The present study showed that the MG decreased RPE scores and increased exercise states. Importantly, the executive function scores (i.e., interference scores and updating scores) of participants in MG significantly increased the following exercise compared to the SMG and the FMG, which meant the improvement of inhibitory control and WM in MG. Besides, the participants in MG had more positive emotional states, including more felt happy and excited (HE); and fewer felt angry and hate (AH). This effect persisted for 40 min after exercise.

The effects of matching on exercise states and emotion

Our study showed no significant differences in HR during exercise, and it is suggested that the music tempo does not affect the completion of the exercise task. Furthermore, our results also found that the MG had

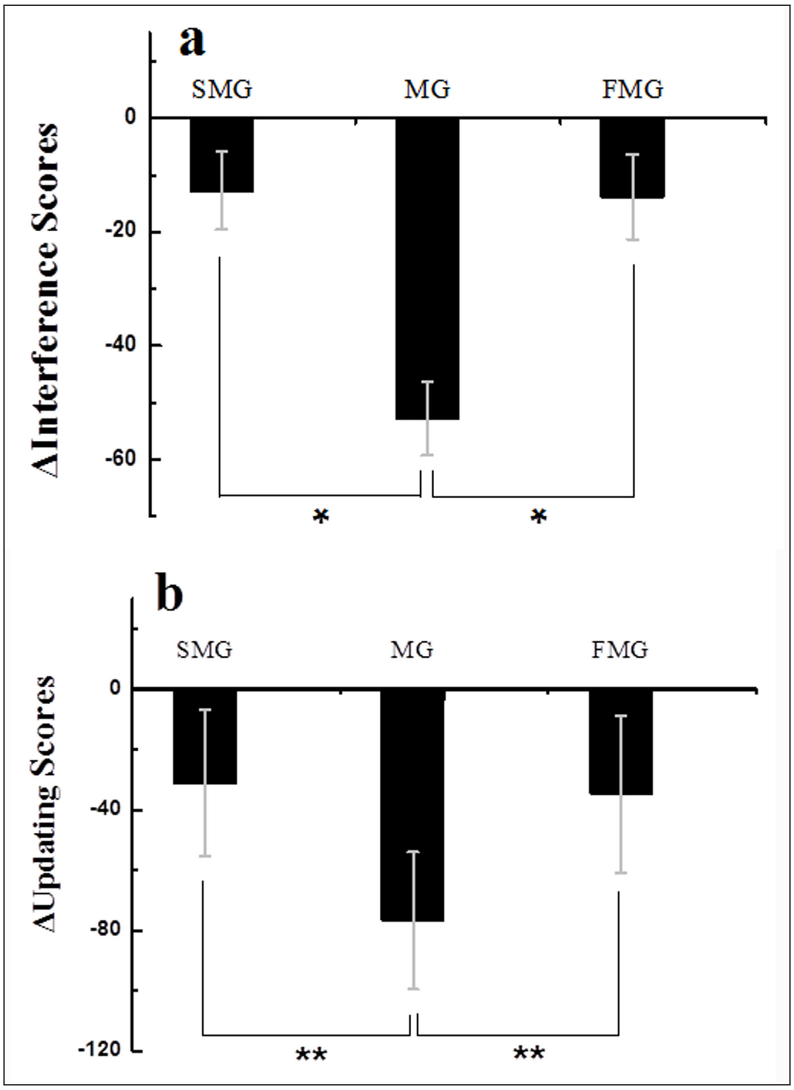

Figure 4: The executive function in different groups.
Note: **(a)** There were significant differences in the ΔInterference scores between the MG and the other two groups. **(b)** There were significant differences in the ΔUpdating scores between the MG and the other two groups. * $p < 0.05$; ** $p < 0.01$.

better exercise states and emotional experience. These findings indicated that acute moderate-intensity (60–70% HRmax) exercise with listening to music was more likely to reduce the subjective fatigue of participants (Potteiger et al., 2000, Sokhadze et al., 2007), which was in line with previous studies. It is suggested that our experimental procedure is successful.

When the tempo of the HR during exercise was consistent with that of the music, the music intervention had more beneficial effects on alleviating subjective fatigue (Shih et al., 2012). Moreover, functional magnetic resonance imaging studies indicated that the combined effects of exercise and synchronous music led to increased activation in the left inferior frontal gyrus (Bigliassi et al., 2018). Furthermore, activation in this brain area was negatively correlated with exertional responses (Bigliassi et al., 2017, Bigliassi et al., 2018). It also might be that the music stimulated the brain areas of the limbic system and reticular formation of the brain stem through auditory conduction. Then, it had a positive effect on psychosomatic states, such as promoting the synthesis of endorphins and inhibiting the release of hypothalamic adrenocorticotropic hormone, through the regulation of the processes in the autonomic nervous systems in the cerebral cortex. In this way, it could be used to regulate cardiovascular systems with blood pressure (Karageorghis and Priest, 2012) and reduce anxiety (Terry et al., 2020). What's more, aerobic exercise affected emotional states beneficially (Edwards et al., 2018). Therefore, the simultaneous matching rhythms of the music and HR during exercise might produce a resonance effect in the brain (Beauregard et al., 1998) which resulted in positive emotional experiences and improved exercise performance (Terry et al., 2020).

The effects of matching on executive function

The participants in MG obtained higher scores in executive function tasks, which supported our hypothesis. That is, the exercise (e.g., running and cycling) with matched music conditions had a more beneficial effect on executive function in young adults. There is some evidence suggesting that aerobic exercise improves executive function through increasing the activation of the prefrontal cortex regions of the brain (Li et al., 2014, Winter et al., 2007). Moderate aerobic exercise increases brain activities of bilateral parietal cortices, bilateral cerebellum, and the left hippocampus, with better performance in the *n*-back task (Chen et al., 2016). Besides, the effects of music training on executive function have been investigated in different populations (Moreno and Farzan, 2015). Music training has been demonstrated to beneficially influence cognitive function by increased global and regional cerebral blood flow as well as increased activation of cellular and metabolic rates in certain networks in the brain. An event-related potential study revealed that acute music training, compared to the control group, significantly increased P200 amplitudes in Go/NoGo task, which indicated that music training had a more beneficial effect on inhibitory control (Moreno et al., 2011).

Compared to mismatched groups, the endogenous brain oscillations may result in better performance in executive function tasks. Recent research suggests that driving brain oscillations with rhythmic stimulation by transcranial magnetic stimulation can especially improve WM performance (Albouy et al., 2017). Mozart's music has been proved to enhance WM, through the dorsal prefrontal cortex activation and the network activity, as well as the evoked specific oscillatory periodicities (Maguire, 2015). Moreover, the selective entrainment of theta oscillations in the brain may regulate brain activity and connection patterns. Similar evidence was also found in transcranial alternating current stimulation study (Violante et al., 2017). These studies suggested that oscillations could serve as aims for controlled interventions into brain function (Albouy et al., 2017).

Notably, synchronous music with HR during exercise could promote endogenous brain oscillations, which would increase the activation of the brain structures and modulate connectivity patterns. Schneider *et al.* recorded oscillations along the longitudinal axis of outdoor running by an accelerometer. They found that a peak frequency at around 3 Hz for the vertical acceleration during running, as well as the HR, musical materials, and electroencephalographic delta activity had similar oscillation patterns (Schneider et al., 2010). It means that the music, as extrinsic oscillation, matching the intrinsic oscillation during exercise.

On the other hand, it is reasonable that this pattern is not suitable for ball games (e.g., basketball and tennis) and other sports. Because the HR and postures (frequency of vertical axis) are not regular during the exercise mentioned above. Additionally, the functional near-infrared spectroscopy studies have shown that the music during synchronized exercise can delay the increase in oxygenation in frontal lobes (Ekkekakis, 2009). The results give reason to speculate that the oscillation may present effects on cerebral oxygen metabolism and cerebral hemodynamics in the frontal regions associated with executive function. Rhythmical stimulation enhanced the theta frequency neural oscillations of the lateral prefrontal cortex and the alpha oscillations in the occipital parietal cortex. WM depends on prioritizing relevant information and restraining irrelevant information (D'Esposito and Postle, 2015). Prioritizing relevant information is associated with theta frequency neural oscillations in the lateral prefrontal cortex and restraining irrelevant information was associated with alpha oscillation in the occipital-parietal cortex (Wallis et al., 2015). This pattern of rhythmic matching strengthens theta and alpha frequency and improves working memory. In brief, these changes may result in improved participants' performance in executive function tasks.

Furthermore, some evidence suggested that positive emotion had more beneficial effects on executive function than neutral and negative emotion (Aldao et al., 2010). Our findings revealed that the participants in the match group had a more positive emotional state with better behavioral performance. This might explain the results of this study.

Limitations and future researches

There are several limitations in this study. Firstly, the music materials in this study were music without lyrics. The previous studies showed that music with or without lyrics had different effects on aerobic exercise (Shih et al., 2012). Moreover, our experiments chose pop music as music materials. However, listening to classical music can improve the cognitive function in young adults (Kramer et al., 1999), and jazz music can lead to better exercise states (Potteiger et al., 2000). Therefore, it is necessary to investigate the effects of exercise with different music styles on executive function. Secondly, there were no significant gender differences in our results ($p > 0.05$), and gender did not play a major role in our study. Consequently, we did not report it in results. However, a few studies reviewed gender differences in synchronizing with beats of the music (Cole and Maeda, 2015, Van Dyck et al., 2015). The effects of negative meant asynchrony were more pronounced for females compared to males (Buhmann et al., 2018). It is possible that the sample size is not large. Hence, future study is still needed to expand the samples' quantity. Thirdly, as mentioned above, the model of exercise with music could not be adapted to other sports (e.g., basketball and tennis). Finally, the behavioral data collected in this study partly revealed the reason for the effects. As a result, in the model of exercise match music, it is also essential to assess the activation and connection of the brain, and to further explore the underlying mechanism, by electrophysiological studies.

Conclusions

To conclude, this study reported the novel findings that compared to unsynchronized condition, moderate intensity aerobic exercise with synchronous music can improve executive function performance (i.e., inhibitory control and WM) in young adults. That is, the tempo matching plays a major role in the more effects of aerobic exercise with music on executive function.

Competing Interests

The authors have no competing interests to declare.

References

Akiyama, K., & **Sutoo, D.** (2013). Role of musical stimuli in dopaminergic brain function. *Music: Social Impacts, Health Benefits and Perspectives*, 83–104.

Albouy, P., Weiss, A., Baillet, S., & **Zatorre, R. J.** (2017). Selective entrainment of theta oscillations in the dorsal stream causally enhances auditory working memory performance. *Neuron*, *94*(1), 193–206. DOI: https://doi.org/10.1016/j.neuron.2017.03.015

Aldao, A., Nolenhoeksema, S., & **Schweizer, S.** (2010). Emotion-regulation strategies across psychopathology: A meta-analytic review. *Clinical Psychology Review*, *30*(2), 217–237. DOI: https://doi.org/10.1016/j.cpr.2009.11.004

Altenmüller, E., & **Schlaug, G.** (2013). Neurologic music therapy: The beneficial effects of music making on neurorehabilitation. *Acoustical Science and Technology*, *34*(1), 5–12. DOI: https://doi.org/10.1250/ast.34.5

Aoun, P., Jones, T., Shaw, G. L., & **Bodner, M.** (2005). Long-term enhancement of maze learning in mice via a generalized mozart effect. *Neurological research*, *27*(8), 791–796. DOI: https://doi.org/10.1179/016164105X63647

Beauregard, M., Leroux, J.-M., Bergman, S., Arzoumanian, Y., Beaudoin, G., Bourgouin, P., & **Stip, E.** (1998). The functional neuroanatomy of major depression: An fMRI study using an emotional activation paradigm. *Neuroreport*, *9*(14), 3253–3258. DOI: https://doi.org/10.1097/00001756-199810050-00022

Bigliassi, M., Karageorghis, C. I., Bishop, D. T., Nowicky, A. V., & **Wright, M. J.** (2018). Cerebral effects of music during isometric exercise: An fMRI study. *International Journal of Psychophysiology, 133*(6), 131–139. DOI: https://doi.org/10.1016/j.ijpsycho.2018.07.475

Bigliassi, M., Karageorghis, C. I., Wright, M. J., Orgs, G., & **Nowicky, A. V.** (2017). Effects of auditory stimuli on electrical activity in the brain during cycle ergometry. *Physiology & Behavior*, *177*, 135–147. DOI: https://doi.org/10.1016/j.physbeh.2017.04.023

Bishop, D. T., Karageorghis, C. I., & **Kinrade, N. P.** (2009). Effects of musically-induced emotions on choice reaction time performance. *Sport Psychologist*, *23*(1), 59–76. DOI: https://doi.org/10.1123/tsp.23.1.59

Borg, E., & **Kaijser, L.** (2006). A comparison between three rating scales for perceived exertion and two different work tests. *Scandinavian Journal of Medicine & Science in Sports*, *16*(1), 57–69. DOI: https://doi.org/10.1111/j.1600-0838.2005.00448.x

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377–381. DOI: https://doi.org/10.1249/00005768-198205000-00012

Brush, C. J., Olson, R. L., Ehmann, P. J., Osovsky, S., & **Alderman, B. L.** (2016). Dose-response and time course effects of acute resistance exercise on executive function. *Journal of Sport & Exercise Psychology*, *38*(4), 396–408. DOI: https://doi.org/10.1123/jsep.2016-0027

Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., & **Rizzolatti, G.** (2005). Listening to action-related sentences modulates the activity of the motor system: A combined tms and behavioral study. *Cognitive Brain Research*, *24*(3), 355–363. DOI: https://doi.org/10.1016/j.cogbrainres.2005.02.020

Buhmann, J., Moens, B., van Dyck, E., Dotov, D. G., & **Leman, M.** (2018). Optimizing beat synchronized running to music. *PLoS One*, *13*(12), e0208702. DOI: https://doi.org/10.1371/journal.pone.0208702

Camm, A. J., Malik, M., Bigger, J. T., Breithardt, G., Cerutti, S., Cohen, R. J., Coumel, P., Fallen, E. L., Kennedy, H. L., & **Kleiger, R. E.** (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 of pacing and electrophysiology. *Circulation*, *93*(5), 1043–1065. DOI: https://doi.org/10.1161/01.CIR.93.5.1043

Chang, Y.-K., & **Etnier, J. L.** (2009). Effects of an acute bout of localized resistance exercise on cognitive performance in middle-aged adults: A randomized controlled trial study. *Psychology of Sport and Exercise*, *10*(1), 19–24. DOI: https://doi.org/10.1016/j.brainres.2012.02.068

Chen, A.-G., Yin, H.-C., Yan, J., & **Yang, Y.** (2011). Effects of acute aerobic exercise of different intensity on executive function. *Acta Psychologica Sinica*, *43*(09), 1055–1062.

Chen, A.-G., Zhu, L.-N., Yan, J., & **Yin, H.-C.** (2016). Neural basis of working memory enhancement after acute aerobic exercise: fMRI study of preadolescent children. *Frontiers in Psychology*, *7*, 1804–1813. DOI: https://doi.org/10.3389/fpsyg.2016.01804

Cole, Z. J., & **Maeda, H.** (2015). Effects of listening to preferential music on sex differences in endurance running performance. *Perceptual and Motor Skills*, *121*(2), 390–398. DOI: https://doi.org/10.2466/06.PMS.121c20x9

Crust, L. (2004). Carry-over effects of music in an isometric muscular endurance task. *Perceptual and Motor Skills*, *98*(3), 985–991. DOI: https://doi.org/10.2466/pms.98.3.985-991

D'esposito, M., & **Postle, B. R.** (2015). The cognitive neuroscience of working memory. *Annual Review of Psychology*, *66*, 115–142. DOI: https://doi.org/10.1146/annurev-psych-010814-015031

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168. DOI: https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., Briand, L., Fossella, J., & **Gehlbach, L.** (2004). Genetic and neurochemical modulation of prefrontal cognitive functions in children. *American Journal of Psychiatry*, *161*(1), 125–132. DOI: https://doi.org/10.1176/appi.ajp.161.1.125

Dustman, R. E., Emmerson, R. Y., Ruhling, R. O., Shearer, D. E., Steinhaus, L. A., Johnson, S. C., Bonekat, H. W., & **Shigeoka, J. W.** (1990). Age and fitness effects on eeg, erps, visual sensitivity, and cognition. *Neurobiology of Aging*, *11*(3), 193–200. DOI: https://doi.org/10.1016/0197-4580(90)90545-B

Edwards, M. K., Rhodes, R. E., Mann, J. R., & **Loprinzi, P. D.** (2018). Effects of acute aerobic exercise or meditation on emotional regulation. *Physiology & Behavior*, *186*, 16–24. DOI: https://doi.org/10.1016/j.physbeh.2017.12.037

Edworthy, J., & **Waring, H.** (2006). The effects of music tempo and loudness level on treadmill exercise. *Ergonomics*, *49*(15), 1597–1610. DOI: https://doi.org/10.1080/00140130600899104

Ekkekakis, P. (2009). Illuminating the black box: Investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. *Journal of Sport & Exercise Psychology*, *31*(4), 505–553. DOI: https://doi.org/10.1123/jsep.31.4.505

Emery, C. F., Hsiao, E. T., Hill, S. M., & **Frid, D. J.** (2003). Short-term effects of exercise and music on cognitive performance among participants in a cardiac rehabilitation program. *Heart & lung*, *32*(6), 368–373. DOI: https://doi.org/10.1016/S0147-9563(03)00120-1

Esch, T., Guarna, M., Bianchi, E., Zhu, W., & **Stefano, G. B.** (2004). Commonalities in the central nervous system's involvement with complementary medical therapies: Limbic morphinergic processes. *Medical Science Monitor*, *10*(6), 6–17.

Frith, E., & **Loprinzi, P. D.** (2018). Experimental effects of acute exercise and music listening on cognitive creativity. *Physiology & Behavior*, *191*, 21–28. DOI: https://doi.org/10.1016/j.physbeh.2018.03.034

Gellish, R. L., Goslin, B. R., Olson, R. E., Mcdonald, A., Russi, G. D., & **Moudgil, V. K.** (2007). Longitudinal modeling of the relationship between age and maximal heart rate. *Medicine and Science in Sports and Exercise*, *39*(5), 822–829. DOI: https://doi.org/10.1097/mss.0b013e31803349c6

Hars, M., Herrmann, F. R., Gold, G., Rizzoli, R., & **Trombetti, A.** (2014). Effect of music-based multitask training on cognition and mood in older adults. *Age Ageing*, *43*(2), 196–200. DOI: https://doi.org/10.1093/ageing/aft163

Hutchinson, J. C., Jones, L., Vitti, S. N., Moore, A., Dalton, P. C., & **O'neil, B. J.** (2018). The influence of self-selected music on affect-regulated exercise intensity and remembered pleasure during treadmill running. *Sport, Exercise, and Performance Psychology*, *7*(1), 80–92. DOI: https://doi.org/10.1037/spy0000115

Jie, Z., & **Ming-Yi, Q.** (2005). A study of development and validation of chinese mood adjective check list. *Chinese Journal of Clinical Psychology*, *13*(1), 9–13. DOI: https://doi.org/10.16128/j.cnki.1005-3611.2005.01.003

Johnson, J. K., Cotman, C. W., Tasaki, C. S., & **Shaw, G. L.** (1998). Enhancement of spatial-temporal reasoning after a mozart listening condition in alzheimer's disease: A case study. *Neurological research*, *20*(8), 666–672. DOI: https://doi.org/10.1080/01616412.1998.11740582

Karageorghis, C. I., & **Priest, D.-L.** (2012). Music in the exercise domain: A review and synthesis (part i). *International Review of Sport and Exercise Psychology*, *5*(1), 44–66. DOI: https://doi.org/10.1080/1750984X.2011.631026

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., Mcauley, E., Harrison, C. R., Chason, J., Vakil, E., Bardell, L., & **Boileau, R. A.** (1999). Ageing, fitness and neurocognitive function. *Nature*, *400*(6743), 418–419. DOI: https://doi.org/10.1038/22682

Lang, P. J., Greenwald, M. K., Bradley, M. M., & **Hamm, A. O.** (1993). Looking at pictures: Affective, facial, visceral, and behavioral reactions. *Psychophysiology*, *30*(3), 261–273. DOI: https://doi.org/10.1111/j.1469-8986.1993.tb03352.x

Larsen, J. T., Norris, C. J., Mcgraw, A. P., Hawkley, L. C., & **Cacioppo, J. T.** (2009). The evaluative space grid: A single-item measure of positivity and negativity. *Cognition & Emotion*, *23*(3), 453–480. DOI: https://doi.org/10.1080/02699930801994054

Li, L., Men, W.-W., Chang, Y.-K., Fan, M.-X., Ji, L., & **Wei, G.-X.** (2014). Acute aerobic exercise increases cortical activity during working memory: A functional MRI study in female college students. *PLoS One*, *9*(6), e99222. DOI: https://doi.org/10.1371/journal.pone.0099222

Loizou, G., & **Karageorghis, C. I.** (2015). Effects of psychological priming, video, and music on anaerobic exercise performance. *Scandinavian Journal of Medicine & Science in Sports*, *25*(6), 909–920. DOI: https://doi.org/10.1111/sms.12391

Maguire, M. J. (2015). Music and its association with epileptic disorders. *Progress in Brain Research*, *217*, 107–127. DOI: https://doi.org/10.1016/bs.pbr.2014.11.023

Miller, E. K., & **Cohen, J. D.** (2001). An integrative theory of prefrontal cortex function. *Annu Rev Neurosci*, *24*, 167–202. DOI: https://doi.org/10.1146/annurev.neuro.24.1.167

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & **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*(1), 49–100. DOI: https://doi.org/10.1006/cogp.1999.0734

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & **Chau, T.** (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. DOI: https://doi.org/10.1177/0956797611416999

Moreno, S., & **Farzan, F.** (2015). Music training and inhibitory control: A multidimensional model. *Annals of the New York Academy of Sciences*, *1337*(1), 147–152. DOI: https://doi.org/10.1111/nyas.12674

Patania, V. M., Padulo, J., Iuliano, E., Ardigò, L. P., Čular, D., Miletić, A., & **De Giorgio, A.** (2020). The psychophysiological effects of different tempo music on endurance versus high-intensity performances. *Frontiers in Psychology*, *11*, 74–92. DOI: https://doi.org/10.3389/fpsyg.2020.00074

Potteiger, J. A., Schroeder, J. M., & **Goff, K. L.** (2000). Influence of music on ratings of perceived exertion during 20 minutes of moderate intensity exercise. *Perceptual and Motor Skills*, *91*(3), 848–854. DOI: https://doi.org/10.2466/pms.2000.91.3.848

Rauscher, F. H., Shaw, G. L., & **Ky, K. N.** (1993). Music and spatial task performance. *Nature*, *365*(6447), 611. DOI: https://doi.org/10.1038/365611a0

Rooks, C. R., Thom, N. J., Mccully, K. K., & **Dishman, R. K.** (2010). Effects of incremental exercise on cerebral oxygenation measured by near-infrared spectroscopy: A systematic review. *Progress in neurobiology*, *92*(2), 134–150. DOI: https://doi.org/10.1016/j.pneurobio.2010.06.002

Rui, S., Ting, Z., Bo, P., Wei-Ji, T., & **Dong-Shi, W.** (2020). Effects of music with aerobic exercise on executive function among college students. *China Sport Science and Technology*, in press.

Salthouse, T. A., Atkinson, T. M., & **Berish, D. E.** (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General*, *132*(4), 566–594. DOI: https://doi.org/10.1037/0096-3445.132.4.566

Schneider, S., Askew, C. D., Abel, T., & **Strüder, H. K.** (2010). Exercise, music, and the brain: Is there a central pattern generator? *Journal of Sports Sciences*, *28*(12), 1337–1343. DOI: https://doi.org/10.1080/02640414.2010.507252

Sesso, G., & **Sicca, F.** (2020). Safe and sound: Meta-analyzing the mozart effect on epilepsy. *Clinical Neurophysiology*, *131*(7), 1610–1620. DOI: https://doi.org/10.1016/j.clinph.2020.03.039

Shih, Y., Huang, R., & **Chiang, H.** (2012). Background music: Effects on attention performance. *Work-a Journal of Prevention Assessment & Rehabilitation*, *42*(4), 573–578. DOI: https://doi.org/10.3233/WOR-2012-1410

Shimizu, N., Umemura, T., Matsunaga, M., & **Hirai, T.** (2018). Effects of movement music therapy with a percussion instrument on physical and frontal lobe function in older adults with mild cognitive impairment: A randomized controlled trial. *Aging & Mental Health*, *22*(12), 1614–1626. DOI: https://doi.org/10.1080/13607863.2017.1379048

Sibley, B. A., Etnier, J. L., & **Le Masurier, G. C.** (2006). Effects of an acute bout of exercise on cognitive aspects of stroop performance. *Journal of Sport and Exercise Psychology*, *28*(3), 285–299. DOI: https://doi.org/10.1123/jsep.28.3.285

Smith, E. E., Jonides, J., Marshuetz, C., & **Koeppe, R. A.** (1998). Components of verbal working memory: Evidence from neuroimaging. *Proceedings of the National Academy of Sciences of the United States of America*, *95*(3), 876–882. DOI: https://doi.org/10.1073/pnas.95.3.876

Sokhadze, T. M., Stewart, C. M., & **Hollifield, M.** (2007). Integrating cognitive neuroscience research and cognitive behavioral treatment with neurofeedback therapy in drug addiction comorbid with posttraumatic stress disorder: A conceptual review. *Journal of Neurotherapy*, *11*(2), 13–44. DOI: https://doi.org/10.1300/J184v11n02_03

Stork, M. J., Kwan, M. Y., Gibala, M. J., & **Martin Ginis, K. A.** (2015). Music enhances performance and perceived enjoyment of sprint interval exercise. *Medicine and Science in Sports and Exercise*, *47*(5), 1052–1060. DOI: https://doi.org/10.1249/MSS.0000000000000494

Stroop, J. R. (1992). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology: General*, *18*(6), 643–662. DOI: https://doi.org/10.1037/h0054651

Svebak, S., & **Murgatroyd, S.** (1985). Metamotivational dominance: A multimethod validation of reversal theory constructs. *Journal of Personality and Social Psychology*, *48*(1), 107–116. DOI: https://doi.org/10.1037/0022-3514.48.1.107

Terry, P. C., Karageorghis, C. I., Curran, M. L., Martin, O. V., & **Parsons-Smith, R. L.** (2020). Effects of music in exercise and sport: A meta-analytic review. *Psychological Bulletin*, *146*(2), 91–117. DOI: https://doi.org/10.1037/bul0000216

van Dyck, E., Moens, B., Buhmann, J., Demey, M., Coorevits, E., Bella, S. D., & **Leman, M.** (2015). Spontaneous entrainment of running cadence to music tempo. *Sports Medicine – Open*, *1*(1), 15. DOI: https://doi.org/10.1186/s40798-015-0025-9

Violante, I. R., Li, L. M., Carmichael, D. W., Lorenz, R., Leech, R., Hampshire, A., Rothwell, J. C., & **Sharp, D. J.** (2017). Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance. *eLife*, *6*, e22001. DOI: https://doi.org/10.7554/eLife.22001

Wallis, G., Stokes, M., Cousijn, H., Woolrich, M., & **Nobre, A. C.** (2015). Frontoparietal and cingulo-opercular networks play dissociable roles in control of working memory. *Journal of Cognitive Neuroscience*, *27*(10), 2019–2034. DOI: https://doi.org/10.1162/jocn_a_00838

Winter, B., Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., Krueger, K., Fromme, A., Korsukewitz, C., & **Floel, A.** (2007). High impact running improves learning. *Neurobiology of learning and memory*, *87*(4), 597–609. DOI: https://doi.org/10.1016/j.nlm.2006.11.003

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