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4 **Comparison of the effects of running and badminton on executive function: a**
5 **within-subjects design**

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17 **Abstract**

18 Multiple cross-sectional studies have shown that regular complex exercises, which
19 require cognitive demands (e.g., decision making) and various motions, are associated
20 with greater positive effects on executive functions compared to simple exercises.
21 However, the evidence of a single bout of complex exercises is mixed, and
22 investigations on the acute effect of complex exercise using a well-controlled within-
23 subjects research design are few. Therefore, we compared the acute effects of complex
24 exercise on inhibitory functions with those of simple running. Twenty young adults
25 performed three interventions, which were running, badminton, and seated rest as a
26 control condition for 10 min each. During each intervention, oxygen consumption and
27 heart rate were monitored. A Stroop test and a reverse-Stroop test were completed
28 before and after each intervention. The intensities of the badminton and running were
29 equivalent. Badminton significantly improved performance on the Stroop task
30 compared to seated rest; however, running did not enhance performance on the Stroop
31 task relative to seated rest. A single bout of complex exercise elicits a larger benefit to
32 inhibitory function than a single bout of simple exercise. However, the benefit of
33 complex exercise may vary depending on the type of cognitive control.

34

35 **Introduction**

36 Regular exercise can prevent cognitive decline and dementia [1]. Moreover, it is
37 thought that exercise has a beneficial effect on executive function, including inhibitory
38 control, working memory, and cognitive flexibility [2]. To clarify what kinds of
39 exercises improve executive functions, researchers have studied both quantitative
40 characteristics (e.g., intensity, duration, and frequency) and qualitative characteristics
41 (e.g., exercise mode and complexity) [3, 4]. Several studies [5-7] showed that complex
42 exercises, including open skill sports (e.g., basketball, tennis, and fencing), have more
43 positive effects on executive functions than simple exercises, such as closed skill sports
44 (e.g., running and swimming). Voss et al. reported results from a meta-analysis
45 indicating that athletes who are experts at complex exercises tend to exhibit superior
46 executive function than simple sports athletes and non-athletes. Complex exercises
47 require the coordination of a variety of motions and cognitive processes, including
48 information pick-up, decision making, visual attention, and inhibition of inappropriate
49 actions.

50 Given that regular exercise is an aggregation of daily single bout exercises, acute
51 complex exercises might have a different influence on executive functions or activate
52 different brain regions than acute simple exercises. We hypothesized that these features
53 of complex exercises might have effects on executive functions that differ from simple
54 exercises. Specifically, we expected that acute complex exercise would result in a
55 greater benefit to executive function than acute simple exercise.

56 There is abundant evidence that acute simple aerobic exercise has a significant
57 effect on executive functions [8, 9]. However, the acute effects of complex exercises
58 have received much less attention [10]. Several studies have compared the effects of the
59 different exercise modes on executive functions, however, results from these studies are

60 inconsistent. Studies that support the idea that cognitive demands of complex exercises
61 yield a positive effect on executive functions include Budde et al.[11] who reported that
62 acute coordinative exercise improved selective attention compared to acute simple
63 circuit training. Additionally, Pesce et al. [12] showed that exercise involving a team
64 game improved immediate memory recall function more than a control condition while
65 circuit training failed to show a similar effect. Lastly, Ishihara et al. [13] reported that
66 both playing tennis matches and participating in tennis drills enhanced executive
67 functions relative to a control condition. However, improvement of executive functions
68 following tennis matches was greater than for the drills.

69 In contrast, other studies have reported that complex exercise impacts executive
70 function to a lesser extent than simple exercise. For example, Gallotta et al. [14]
71 reported that the acute effect of brief basketball mini games on selective attention was
72 smaller than both a running program and a control condition (sitting in an academic
73 class). O'Leary et al. [15] measured inhibitory function after participants walked on a
74 treadmill, played a video game, played an active video game, or sat and rested. The
75 authors reported that walking on a treadmill enhanced inhibitory function compared
76 with playing a videogame and seated rest. Playing active videogame that requires
77 cognitive demands resulted in inhibitory function intermediate to walking and the video
78 game. Kamijo and Abe [16] reported that cycling enhanced executive function while
79 cycling with the cognitive task did not improve executive function but increased
80 cognitive fatigue.

81 The conflicting evidence outlined above might be due to the methods employed.
82 Many studies use heart rate (HR) as a measure of exercise intensity to equate exercise
83 conditions [11-16]. However, it is known that HR is sensitive to many factors such as
84 gender, exercise mode, emotion, posture, and environmental conditions [17, 18] and so

85 different values for HR may be due to factors other than exercise intensity. To reduce
86 the possibility of the influence of these factors, we included oxygen consumption (VO_2)
87 and carbon dioxide output (VCO_2) measures in addition to HR to monitor the intensity
88 of physical activity in our experiment.

89 Another issue is several previous studies were conducted in a field setting, such
90 as a physical education program or sports training. Experiments in a field setting can be
91 affected by extraneous variables such as weather condition, motivation, day of the
92 week, and anxiety of participants in an unusual situation. To our knowledge, O’Leary et
93 al. [15] and Kamijo and Abe [16] are the only studies on this topic that were conducted
94 in a laboratory setting. Although the exercise tasks in Kamijo and Abe’s experiment
95 were well controlled in terms of intensity, their complex exercise condition was
96 artificial, involving cycling while performing an unrelated cognitive task. In order to
97 resolve the discrepancies in the literature, well-controlled and naturalistic laboratory
98 studies are required. This is the goal of our paper.

99 To further investigate the acute effects of complex exercises on executive
100 functions, we compared the impact of a single bout of complex exercise on inhibitory
101 function with that of a simple aerobic exercise using a within-subject design employing
102 natural exercises, running and badminton. We monitored exercise intensity via HR,
103 VO_2 , and VCO_2 . We chose Badminton as the complex exercise for this study because it
104 involves various motions such as jumping and racket swinging as well as cognitive
105 demands such as strategy, and shot choice/placement.

106 We hypothesized that the change of inhibitory function after badminton will be
107 greater than the changes after running. We measured responses to a modified Stroop
108 task and a reverse Stroop task before and after sessions of badminton, running, and
109 seated rest.

110

111 **Materials and Methods**

112 **Participants**

113 Sample size was calculated using power analysis for a one-way repeated
114 measures ANOVA with partial eta squared (η_p^2) of 0.10, power ($1 - \beta$) of 0.80,
115 intraclass correlation coefficient of 0.5 and alpha at 0.05. This analysis indicated that a
116 sample size of 16 was adequate. Participants consisted of undergraduate students from
117 Tohoku Gakuin University who volunteered to participate in the study. A total of 20
118 healthy participants (8 men, 12 women) were included in the final analysis. All
119 participants were determined to be free of any cardiopulmonary and metabolic disease
120 and visual disorder. The participants were asked to refrain from alcohol use and
121 strenuous physical activity for 24 h before each experiment, and from smoking, food or
122 caffeine consumption for 2 h preceding the experiments. Written informed consent was
123 obtained from all participants before the first experiment. The Human Subjects
124 Committee of Tohoku Gakuin University approved the study protocol. Table 1 shows
125 the characteristics of the participants.

126 Table 1. *Characteristics of the participants (mean \pm SE).*

Variable	Total ($N = 20$)	Men ($N = 8$)	Women ($N = 12$)
Age (years)	20.9 \pm 0.2	20.6 \pm 0.4	21.1 \pm 0.2
Height (cm)	164.3 \pm 0.4	174.9 \pm 1.7	157.3 \pm 1.8
Weight (kg)	59.8 \pm 0.7	73.7 \pm 0.9	50.6 \pm 2.0
BMI ($\text{kg} \cdot \text{m}^{-2}$)	21.9 \pm 0.9	24.1 \pm 0.9	20.4 \pm 0.6
VO ₂ peak ($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	44.6 \pm 1.3	50.5 \pm 1.7	40.7 \pm 0.9
HRpeak (bpm)	197.0 \pm 1.5	195.8 \pm 3.7	197.8 \pm 1.5

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129 **Procedures**

130 **Day 1.** Participants were required to visit the sports physiology laboratory in the
131 gymnasium on four different days (average interval, 5.8 ± 1.4 days). During the first
132 visit, each participant received a brief introduction to this study and completed informed
133 consent. Their height and weight were measured using a stadiometer and a digital scale,
134 respectively. Next, the complete group version of the Stroop/reverse-Stroop color-word
135 test by Hakoda and Sasaki [19] was administered to familiarize participants with the test
136 of inhibitory function. A graded exercise test was subsequently conducted to determine
137 peak of VO_2 (VO_{2peak}) and HR_{peak} .

138 **Day 2-4 (experimental sessions).** Laboratory visits 2, 3, and 4 were experimental
139 sessions. To minimize any order or learning effects, the orders of the experimental
140 sessions were counterbalanced. After arrival at the laboratory, the participants wore a
141 HR monitor (Model RS800cx; Polar Electro Oy, Kempele, Finland) and they rested on a
142 comfortable chair for 10 min. In the experimental sessions, the participants completed
143 the Stroop/reverse-Stroop test (duration: 6 min) before and after each intervention. After
144 the pre-test of Stroop/reverse-Stroop test, the participants were fitted with a portable
145 indirect calorimetry system (MetaMax-3B; Cortex, Leipzig, Germany). This took 1 min
146 and participants rested on a chair for an additional 3 min. For the badminton
147 intervention, the participants moved from the laboratory to a badminton court, which
148 took 2 min. For both the running and the control interventions, the participants walked
149 on a treadmill at $4.2 \text{ km} \cdot \text{h}^{-1}$ for 2 min, which served as a counterpart to the move from
150 the laboratory to the badminton court. Subsequently, the participants performed each
151 intervention. Based on the protocol of Budde et. al. [11], the duration of the intervention
152 was set to 10 min. After each intervention, the participants returned to the laboratory or
153 walked on the treadmill for 2 min, and then rested for 3 min on a chair. After that, they

154 removed the indirect calorimetry system, completing the post-test of Stroop/reverse-
155 Stroop test, which took 6 min.

156 In the badminton intervention, the participants played a singles game against one
157 of the two investigators who had experience playing badminton. The investigators
158 played at a level of proficiency that matched the participant's level and also provided
159 the participants with advice for improvement during the games. During the game, the
160 scores were not recorded and "victory or defeat" was not determined. In the running
161 intervention, the participants ran on a treadmill. Running speed was set according to
162 each participant's 75%VO₂peak, which has been previously shown to be the intensity
163 equal to that of the badminton intervention [20]. In the control intervention, the
164 participants were seated on a comfortable chair with their smart phones and were
165 instructed to spend time operating their smartphones as normal. Oxygen consumption,
166 VCO₂, and HR were monitored throughout each experimental session. Physiological
167 measures for the last 7 min were averaged, and the rating of perceived exertion (RPE)
168 was evaluated at the end of each intervention.

169

170 **Aerobic fitness assessment**

171 Participants performed the graded exercise test on a motor-driven treadmill
172 (O2road, Takei Sci. Instruments Co., Niigata, Japan) to volitional exhaustion. The initial
173 speed was set at 7.2 to 9.6 km·h⁻¹, according to the estimated physical fitness level of
174 each participant. Each speed lasted 2 min and the speed was increased by 1.2 km·h⁻¹
175 until volitional exhaustion. The portable indirect calorimetry system (MetaMax-3B)
176 measured VO₂ and VCO₂, and the average of the final 30 s was defined as the peak
177 oxygen consumption (VO₂peak). The Polar HR monitor (Model RS800cx) was used to
178 measure HR during the test, and RPE was obtained at the end of each stage. Volitional

179 exhaustion was reached based on the following criterion: 1) $RPE \geq 17$, 2) $HR \geq 95\%$ of
180 age-predicted HR_{max} (220 minus age), and 3) a respiratory exchange ratio (RER
181 $VCO_2 \cdot VO_2^{-1} \geq 1.10$.

182

183 **Inhibitory function tasks**

184 We assessed each participant's inhibitory function by the Stroop/reverse-Stroop
185 test which is composed of a Stroop task and a reverse-Stroop task. The Stroop/reverse-
186 Stroop test is a pencil and paper exercise that requires manual matching rather than oral
187 naming of items. It consists of four subtests arranged in the following order: Test 1 is a
188 neutral task that serves as the control for the reverse-Stroop test. Here, a color name
189 (e.g., red) in black ink is in the leftmost column and five different color patches (red,
190 blue, yellow, green, and black) are placed in right side columns. Participants are asked
191 to check the patch corresponding to the color name. Test 2 is the reverse-Stroop test.
192 Here, a color name (e.g., red) written using a colored ink (e.g., blue) is in the leftmost
193 column and five different color patches are in the right-side columns. Participants are
194 instructed to check the patch corresponding to the color name in the leftmost column.
195 Test 3 is a neutral task that serves as the control for the Stroop test. Here, a color patch
196 (e.g., red) is in the leftmost column and five different color names in black ink are in the
197 right-side columns. Participants are asked to check the color name corresponding to the
198 color patch in the leftmost column. Test 4 is the Stroop test in which a color name (e.g.,
199 red) written using a colored ink (e.g., blue) is in the leftmost column and five color
200 names in black ink are in the-right side columns. Participants are instructed to check a
201 word corresponding to the color of the word in the leftmost column. Each subtest
202 consists of 100 items and the materials are printed on an A3-size paper.

203 The Stroop/reverse-Stroop test includes practice trails (10 items in 10 s) that
204 precede each subtest. In each subtest, participants were instructed to check as many
205 correct items as possible in 60 s. Assessment of inhibitory function was defined as the
206 difference in correct responses between neutral and incongruent tasks. In accordance
207 with Etnier and Chang [21], the performances in Tests 1 and 3 were used as indices of
208 information processing speed and those in Tests 2 and 4 as indices of inhibitory
209 function.

210

211 **Statistical analysis**

212 All measurements were described as mean \pm standard error. Statistical analyses
213 were conducted using IBM SPSS 25 (SPSS Inc., Chicago, IL, USA). To examine the
214 exercise intensity of each intervention, %HRmax, %VO₂peak, RER, and RPE were
215 compared using one-way repeated ANOVAs with within-subject factor of mode
216 (running, badminton, and control) and Bonferroni multiple comparison tests separately.

217 The Stroop tasks (Tests 3 and 4) and reverse-Stroop tasks (Tests 1 and 2) were
218 compared using three-way repeated ANOVAs with within-subject factors of condition
219 (neutral and incongruent), time (pre- and post-test), and mode (running, badminton, and
220 seated rest). When any significant interactions were noted, two-way repeated ANOVAs
221 with within-subject factors of time and mode as post hoc analysis were conducted
222 within each subtest. A significant interaction in two-way repeated ANOVA indicates
223 different changes in performance (pre-test minus post-test) among the interventions. If
224 an interaction was significant, differences in performance changes for each intervention
225 were compared using paired *t* tests. To control for significance level through a series of
226 analyses for the Stroop and reverse-Stroop tasks, the significance levels in each analysis
227 were adjusted by Bonferroni inequality: significance levels of three-way repeated

228 ANOVAs, two-way repeated ANOVAs, and paired *t* tests were set at $p = .05$, $p = .025$,
229 and $p = .008$, respectively. Partial eta squared (η_p^2) was calculated as effect size of
230 interactions and main effects in repeated ANOVAs. Cohen's *d* was also calculated using
231 Bonferroni multiple comparison and paired *t* tests.

232

233 **Results**

234 **Intensity of interventions**

235 Table 2 presents the intensities for each intervention. One-way repeated
236 ANOVAs for %VO₂peak, %HRpeak, RER, and RPE revealed the significant main
237 effects ($F(2, 38) \geq 26.4$, $p < .001$, $\eta_p^2 \geq 0.58$). The % VO₂peak, %HRpeak, RER, and
238 RPE during both the badminton and running interventions were significantly higher
239 than those during the control intervention ($p < .001$, Cohen's $d \geq 1.40$). Differences in
240 all intensity measures between the badminton and running interventions were not
241 significant ($p \geq .318$, Cohen's $d \leq |0.38|$).

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251 Table 2. *Intensities of each intervention (mean \pm SE).*

Variable	Intervention	Total (N = 20)
%VO ₂ peak (%)	Badminton	76.3 \pm 2.1 *
	Running	72.7 \pm 1.6*
	Seated rest	9.5 \pm 0.4
%HRpeak (%)	Badminton	80.9 \pm 1.4 *
	Running	81.1 \pm 1.8 *
	Seated rest	37.5 \pm 1.2
RER (VCO ₂ · VO ₂ ⁻¹)	Badminton	0.98 \pm 0.01 *
	Running	0.97 \pm 0.02 *
	Seated rest	0.85 \pm 0.01
RPE	Badminton	12.9 \pm 0.4 *
	Running	13.6 \pm 0.5 *
	Seated rest	6.1 \pm 0.1

252 * Significantly different from seated rest; $p < .05$ at Bonferroni multiple comparison
253 tests.
254

255 Stroop task

256 Table 3 shows the cognitive performances for each intervention. For the Stroop
257 tasks (Tests 3 and 4), three-way repeated ANOVA found a significant interaction
258 between condition, time, and mode ($F(2, 38) = 4.2, p = .022, \eta_p^2 = 0.18$). To analyze
259 the significant interaction, two-way repeated ANOVA was conducted separately for
260 Tests 3 and 4. For Test 3, no significant interaction ($F(2, 38) = 0.9, p = .419, \eta_p^2 = .04$)
261 and no significant main effect of mode ($F(2, 38) = 1.7, p = .201, \eta_p^2 = 0.08$) were
262 observed; however, a significant main effect of time ($F(1, 19) = 63.1, p < .001, \eta_p^2 =$
263 $.77$) was found. For Test 4, a two-way repeated ANOVA revealed a significant
264 interaction ($F(2, 38) = 5.6, p = .007, \eta_p^2 = .23$) and a significant main effect of time (F
265 $(1, 19) = 31.7, p < .001, \eta_p^2 = .63$); however, a main effect of mode was not significant
266 ($F(2, 38) = 0.4, p = .648, \eta_p^2 = .02$). Figure 1 shows the changes in performance for

267 each intervention. As the interaction was significant, differences in the changes in Test
268 4 for each intervention were compared using the paired t tests. The change in the
269 badminton intervention was significantly greater than that in the control intervention (t
270 (19) = 3.6, $p = .002$, Cohen's $d = 0.80$), while the change in the running intervention
271 was not greater than that in the control (t (19) = 1.3, $p = .207$, Cohen's $d = 0.29$). No
272 difference between the badminton and running interventions was observed (t (19) = 1.8,
273 $p = .082$, Cohen's $d = 0.44$).

274

275 Table 3. *Cognitive performances in each intervention (mean \pm SE).*

Task	Condition	Intervention	Pre-test ($N = 20$)	Post-test ($N = 20$)
Stroop task	Neutral (Test 3)	Badminton	53.6 \pm 1.2	57.1 \pm 1.4
		Running	55.0 \pm 1.3	57.2 \pm 1.2
		Control	52.6 \pm 1.5	56.0 \pm 1.6
	Incongruent (Test 4)	Badminton	48.8 \pm 1.5	53.8 \pm 1.7
		Running	50.3 \pm 1.6	52.9 \pm 1.4
		Control	49.9 \pm 1.8	51.2 \pm 1.7
Reverse- Stroop task	Neutral (Test 1)	Badminton	73.0 \pm 1.6	76.9 \pm 1.6
		Running	74.2 \pm 1.3	75.9 \pm 1.8
		Control	71.1 \pm 2.3	74.3 \pm 1.8
	Incongruent (Test 2)	Badminton	60.6 \pm 1.7	60.7 \pm 2.3
		Running	61.0 \pm 1.9	60.7 \pm 1.6
		Control	60.3 \pm 2.1	60.5 \pm 1.9

276

277 **Fig 1. Comparisons of the changes in performances (pre-test minus post-test)**

278 **between modes in each subtest of the Stroop/reverse-Stroop test.** Test 1 is reverse-

279 Stroop neutral test, Test 2 is a reverse-Stroop incongruent test, Test 3 is a Stroop neutral

280 test, and Test 4 is a Stroop incongruent test. Error bars represent standard error. The

281 asterisk (*) indicates a significant difference identified by paired t tests ($p = .008$

282 adjusted by Bonferroni inequality).

283

284 **Reverse-Stroop task**

285 For the reverse-Stroop tasks (Tests 1 and 2), three-way repeated ANOVA found
286 a significant interaction between condition and time ($F(2, 38) = 8.6, p = .009, \eta_p^2 = .31$).
287 To analyze this significant interaction, two-way repeated ANOVAs were conducted for
288 Tests 1 and 2. For Test 1, no significant interaction ($F(2, 38) = 1.0, p = .378, \eta_p^2 = .050$)
289 and no significant main effect of mode ($F(2, 38) = 1.9, p = .168, \eta_p^2 = 0.09$) were
290 noted; however, a significant main effect of time ($F(1, 19) = 18.2, p < .001, \eta_p^2 = .49$)
291 was found. For Test 2, no significant interaction ($F(2, 38) < 0.1, p = .975, \eta_p^2 < .01$)
292 and no significant main effects of mode ($F(2, 38) = 0.7, p = .937, \eta_p^2 < .01$) and time (F
293 ($1, 19) < 0.1, p = .999, \eta_p^2 < .01$) were observed.

294

295 **Discussion**

296 This study aimed to investigate the effect of brief acute complex exercise on
297 inhibitory functions by comparing the effect of badminton with the effect of running on
298 inhibitory function. The main findings of this study were that badminton increased
299 performance in inhibitory function, as shown in the improved performance on the
300 Stroop incongruent test (Test 4), compared to seated rest, while treadmill running did
301 not have a similar effect. Furthermore, changes in performance in the neutral tests
302 (Tests 1 and 3), which served as indices of information processing speed, were not
303 influenced by exercise. These findings indicate that a single bout of complex exercise
304 may selectively improve inhibitory functions compared to simple exercise. However,
305 neither badminton nor running influenced the reverse-Stroop incongruent test (Test 2).
306 It has been suggested that the reverse-Stroop effect is attributable to brain structures that
307 differ from those in Stroop effects [22, 23]. If this is the case, perhaps, complex exercise
308 impacts brain structures associated with the Stroop effect to a greater extent than those

309 structures associated with the reverse-Stroop effect. Though we cannot make a claim
310 regarding the reverse-Stroop interference, the balance of our results supports our
311 hypothesis that acute complex exercise has a greater effect on executive functions than
312 acute simple exercises.

313 There were no differences in intensity between the badminton and running
314 interventions, indicating that both interventions were equally categorized as high
315 intensity [24]. In particular, it should be noted that there was no difference of RER
316 ($\text{VCO}_2 \cdot \text{VO}_2^{-1}$) between the badminton and running interventions. Statistically
317 equivalent RERs in badminton (0.98 ± 0.01) and running (0.97 ± 0.02) showed that both
318 exercises were the same not only in terms of aerobic energy expenditure but also in
319 anaerobic energy expenditure. Therefore, differences in the effects on cognitive
320 performance between the badminton and running interventions can be attributed to
321 differences in cognitive demand and motions.

322 The effects of running on changes in performance did not significantly differ
323 from those of control condition in each subtest. Our finding that simple aerobic exercise
324 for 10 min did not benefit cognitive functions is consistent with Chang et al. [8]. These
325 authors reported significant effects of moderate to very high intensity exercise on
326 cognitive functions when the duration of exercise was greater than 11 min. However,
327 the effects of brief exercise of less than 10 min are small and negative. Given Chang et
328 al.'s results, the effect of high intensity running in our study was possibly counteracted
329 by the short exercise duration. Thus, the absence of a significant effect of running on
330 cognitive functions is not unexpected. Furthermore, the effect size (Cohen's $d = 0.29$) of
331 the running intervention in our study is comparable to those in recently reported meta-
332 analyses [8, 9].

333 In contrast with running, badminton increased performance compared to seated
334 rest in the Stroop incongruent test (Test 4). Although the pre-intervention versus post-
335 intervention change in the badminton condition did not differ significantly from that of
336 the running condition, the effect size between badminton and running was not small
337 (Cohen's $d = 0.44$). Changes in performance associated with the running intervention
338 were intermediate between seated rest and badminton (see Fig 1). These results suggest
339 that the cognitive aspects of badminton provide benefits to inhibitory cognitive function
340 over and above the effect of the running. In badminton, players are required to not only
341 grasp the speed and orbit of the shuttle, spatial position of the opponent, but also to
342 choose appropriate shots (e.g., clear, smash, or drop) and perform them. Such cognitive
343 demands could activate the regions of the brain concerned with executive functions. We
344 conclude that the large effect of the badminton intervention on executive function was
345 due to the cognitive demands required to play the game.

346 Our observation that badminton enhanced inhibitory function to a greater extent
347 than running supported our hypothesis, indicating that the influence of cognitive
348 demands during brief complex exercises is greater than the effects of inefficient
349 exercise. This is consistent with previous studies [11, 12, 25]. However, our observed
350 effects of complex exercise might be restricted to short durations. The effect of complex
351 exercise might be small or negative if exercise duration is extended. Kamijo and Abe
352 [16] reported that 20 min of cycling enhanced executive function while 20 min of
353 cycling with the cognitive task did not improve executive function but increased
354 cognitive fatigue. One possible interpretation of these results is that cognitive fatigue
355 induced by cognitive demand during exercise may cancel the positive effects of acute
356 exercise on executive functions. This interpretation of Kamijo and Abe [16] might
357 explain the results of Gallotta et al [14]. For instance, cognitive demands during

358 exercises might activate the regions of the brain concerned with executive functions
359 (e.g., the prefrontal cortex, anterior cingulate cortex) for a short duration. However, that
360 activation might be gradually overloaded and attenuate the performance of executive
361 functions if exercise duration is extended. This speculation is based on the assumption
362 that complex exercises activate parts of the brain concerned with executive functions
363 more than simple exercises. In order to confirm these assumptions, neuroimaging (e.g.,
364 fMRI and fNIRS) and/or electrophysiological evaluations (e.g., ERP P3) are required.

365 In contrast to the Stroop tasks, we did not observe any differences between
366 badminton and running in the reverse-Stroop tasks. Performance in the reverse-Stroop
367 incongruent test (Test 2) was not influenced by mode, time, or interaction ($p \geq .702$, η_p^2
368 $\leq .02$). This is inconsistent with a few previous studies [26, 27] that have demonstrated
369 that the reverse-Stroop effect is a sensitive index of inhibitory functions for a single
370 bout of exercise. Other study [22] reported that the reverse-Stroop effect differs from
371 the Stroop effect depending on the order the conditions are presented. Furthermore, it
372 has been reported that the Stroop and reverse Stroop effects are mediated by different
373 brain regions [23, 28]. However, the reverse Stroop effect has not been extensively
374 investigated and interpretation of the data is not clear. The mechanisms and the validity
375 of the reverse-Stroop task need further investigations.

376 One limitation of this study was that the badminton intervention differed from a
377 real badminton match. Victory or defeat was not determined, and the investigators as
378 opponents provided participants tips to improve their game. Therefore, the participants
379 may not have experienced any psychological pressure. In a real badminton match,
380 psychological pressure and stress may influence inhibitory function. Second, none of
381 the participants in this study were experienced badminton players. If well-trained
382 badminton players participated, the observed results may differ. This is because the

383 specific motions and cognitive demands in badminton are overlearned by experienced
384 player and are no longer complex.

385

386 **Conclusions**

387 In conclusion, a single bout of a short duration complex exercise selectively
388 enhances inhibitory function relative to a short duration simple exercise. Cognitive
389 demands required in a complex exercise may result in a greater positive effect on
390 executive functions than the negative effect of less efficient motions. However, short
391 duration complex exercise did not improve the performance in the reverse-Stroop
392 incongruent test. The influence of a short duration complex exercise may vary with the
393 type of cognitive tasks.

394

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398

399 **References**

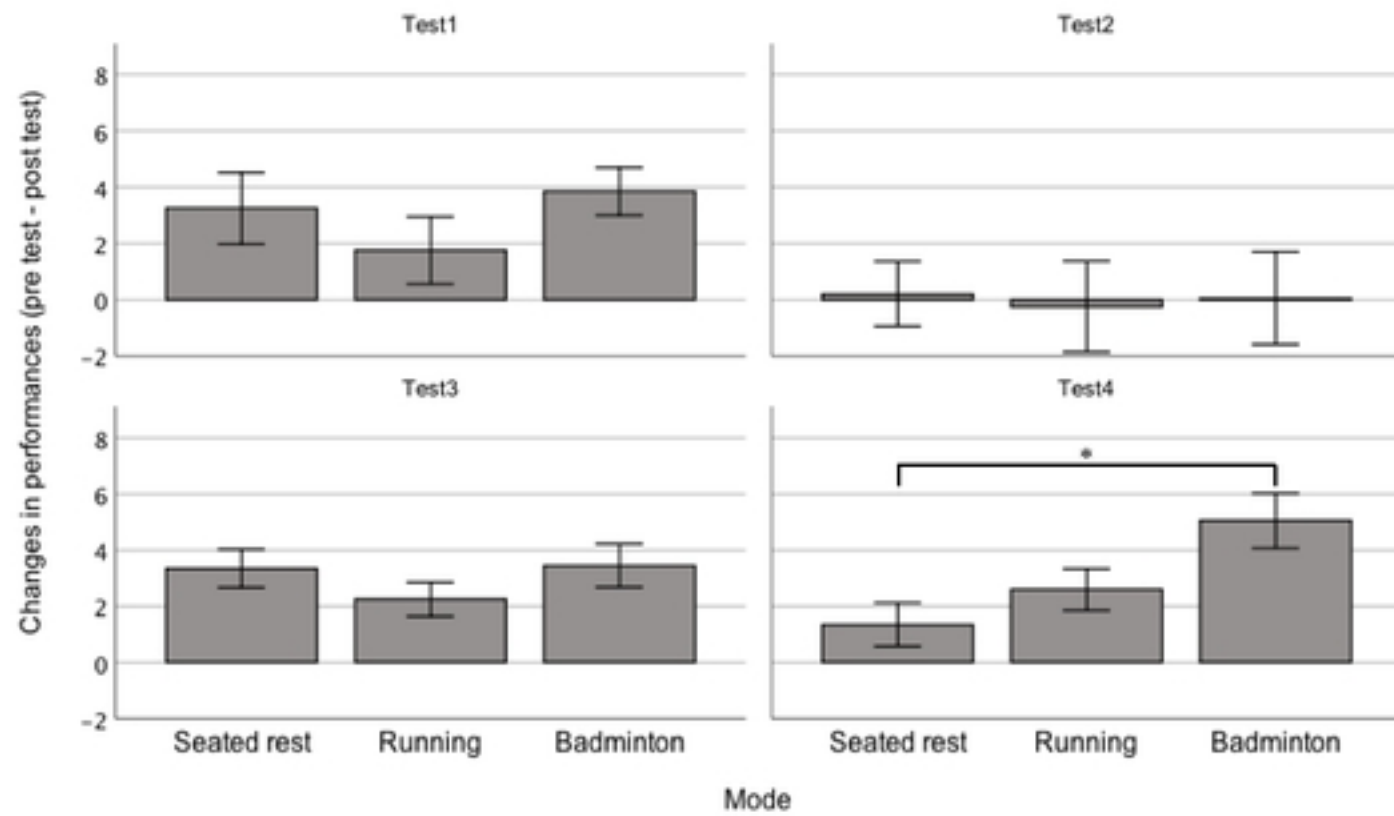
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