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Slowed response to peripheral visual stimuli during strenuous exercise

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Running Head: visual perception during exercise

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22 Abstract (238)

23 Recently, we proposed that strenuous exercise impairs peripheral visual perception
24 because visual responses to peripheral visual stimuli were slowed during strenuous exercise.
25 However, this proposal was challenged because strenuous exercise is also likely to affect the
26 brain network underlying motor responses. The purpose of the current study was to resolve
27 this issue. Fourteen participants performed a visual reaction-time (RT) task at rest and while
28 exercising at 50% (moderate) and 75% (strenuous) peak oxygen uptake. Visual stimuli were
29 randomly presented at different distances from fixation in two task conditions: the Central
30 condition (2° or 5° from fixation) and the Peripheral condition (30° or 50° from fixation). We
31 defined premotor time as the time between stimulus onset and the motor response, as
32 determined using electromyographic recordings. In the Central condition, premotor time did
33 not change during moderate (167 ± 19 ms) and strenuous (168 ± 24 ms) exercise from that at
34 rest (164 ± 17 ms). In the Peripheral condition, premotor time significantly increased during
35 moderate (181 ± 18 ms, $P < 0.05$) and strenuous exercise (189 ± 23 ms, $P < 0.001$) from that
36 at rest (173 ± 17 ms). These results suggest that increases in Premotor Time to the peripheral
37 visual stimuli did not result from an impaired motor-response network, but rather from
38 impaired peripheral visual perception. We conclude that slowed response to peripheral visual
39 stimuli during strenuous exercise primarily results from impaired visual perception of the
40 periphery.

41 **Key Words:** brain, reaction time, premotor time, vision, central nervous system

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43

44 **1. Introduction**

45

46 Many sports require visual perceptual skills under physiological stress. Recently, we
47 found that strenuous exercise impaired the speed of responses to peripheral visual stimuli,
48 and based on these findings we proposed that strenuous exercise impairs peripheral visual
49 perception [1]. However, this proposal was challenged because of the inherent limitation in
50 assessing visual perception with a reaction-time (RT) task in which a motor response is
51 required [17]. Thus, as strenuous exercise is likely to affect the neuronal network required for
52 motor responses, this could have been the source of the slower motor responses, rather than
53 impaired perception [17].

54 In a series of studies that assessed peripheral visual perception during exercise, we
55 calculated the premotor time as the amount of time needed by the central nervous system to
56 process a visual stimulus, develop motor output, and conduct a motor command to the
57 periphery [14]. Several cortical and subcortical brain areas are recruited for manual motor
58 responses [18]. Furthermore, it has been shown that primary motor cortex (leg area)
59 [9,12,19,20], supplementary motor area [9,12], cerebellum [9,12], and insular cortex
60 [9,19,20] are involved in dynamic exercise. As suggested by Vaillancourt & Christou [17],
61 given that metabolic resources are limited in the brain when multiple tasks are performed
62 simultaneously, increased activation in brain areas involved in strenuous exercise might
63 interfere with those that control the manual motor response used in reaction-time tasks
64 similar to ours. However, to what extent this is the case remains to be clarified
65 experimentally.

66 To address this issue, here we compare the effects of strenuous exercise on premotor
67 time to centrally and peripherally presented visual stimuli. We hypothesized that if the slowed

68 response to peripheral stimuli during strenuous exercise is caused by difficulties in peripheral
69 perception, premotor time should only increase if stimuli are presented peripherally.
70 Alternatively, if it is caused by a general impairment in motor output, premotor time during
71 strenuous exercise should increase when stimuli are presented centrally as well as
72 peripherally.

73 The purpose of this study was to examine whether the slowed response to peripheral
74 visual stimuli during strenuous exercise results from impaired peripheral visual perception or
75 from a general impairment in motor control. The present study will provide new insight into
76 the effects of strenuous exercise on human visual perception.

77

78 **2. Material and methods**

79

80 *2.1. Participants*

81 Fourteen male participants (age = 23.4 ± 2.2 years; height = 1.70 ± 0.06 m; weight =
82 67.0 ± 6.5 kg; peak oxygen uptake [$\dot{V}O_2$]: 44.7 ± 5.0 ml/kg/min) gave written informed
83 consent to participate in this study. Participants had normal or corrected-to-normal vision and
84 no history of cardiovascular, cerebrovascular, or respiratory disease. All experimental
85 procedures were approved by the local ethics committee of Fukuoka University and were in
86 accordance with the Declaration of Helsinki.

87

88 *2.2. Experimental procedure*

89 The experiment was performed over three non-consecutive days. In the laboratory,
90 the ambient temperature was between 21 and 23 °C, and the relative humidity was less than
91 50%. Before the main experiments, participants performed a maximal exercise test until
92 exhaustion on a cycle ergometer (75XLII, COMBI Wellness, Tokyo, Japan). The maximal

93 exercise test was terminated when participants were unable to maintain a pedaling rate of 50
94 rpm. Ventilatory parameters were measured using a gas analysis system (ARCO-2000, ARCO
95 System, Chiba, Japan). Peak $\dot{V}O_2$ was determined as the highest oxygen uptake attained
96 during the maximal exercise test. A few days before the main experiments, participants
97 performed practice trials. They completed practice at least two blocks (120 trials) sitting on
98 the cycle ergometer and while cycling until they were familiar with the task. We expect that
99 these practice blocks minimize the possibility that learning affects the results.

100 On experimental days, participants performed RT tasks after they had adapted to a
101 dark environment. We used two visual conditions (Central and Peripheral) that differed in
102 how far away the visual stimuli were from fixation (central or peripheral visual fields). These
103 visual conditions were blocked, and each one was tested on two different days, separated by
104 at least 3 days. The condition order was counterbalanced across participants. Figure 1A
105 shows the experimental protocol. At the beginning of the experiment, RT was measured for 3
106 min while participants rested on the cycle ergometer (baseline, or at-rest measurement). One
107 minute following the at-rest measurement, participants gradually cycled the ergometer up to
108 50% (moderate: 114.2 ± 14.1 watts) and then 75% peak $\dot{V}O_2$ (strenuous: 178.5 ± 20.3 watts).
109 Pedaling rate was freely chosen by each participant, and the duration of each workload was 6
110 min and 30 s. RT was measured 3 min after the increase in workload for each case.

111

112 *Insert Figure 1 about here*

113

114 2.3. RT measurement

115 We used light emitting diodes (LED) as visual stimuli. A green LED served as the
116 fixation point (34 cd/m^2), and was located 58 cm in front of the participants and aligned to the
117 midpoint between their eyes. The response stimuli were eight yellow LEDs (537 cd/m^2) that

118 were positioned on a horizontal arc at 2°, 5°, 30°, and 50° to the right (+) and left (–) of the
119 fixation LED, and equidistant (58 cm) from the midpoint between the eyes (Figure 1B). A
120 microcontroller (PIC16F84, Microchip Technology Inc., USA) was used to light up the
121 yellow LEDs, and participants were instructed to respond to this signal as quickly as possible
122 by releasing a button on the right handlebar that was otherwise kept pressed with the right
123 thumb. The RT was defined as the time between stimulus onset and the release of the button.
124 In the Central condition, visual stimuli were randomly presented at the four positions closest
125 to fixation ($\pm 2^\circ$ or $\pm 5^\circ$), and we can assume that participants oriented attention towards a
126 narrow area of the visual field in this condition (Figure 1C). Likewise, in the Peripheral
127 condition, visual stimuli were presented at the four peripheral locations ($\pm 30^\circ$ or $\pm 50^\circ$), and
128 the participants presumably oriented visual attention towards a larger area of the visual field
129 (Figure 1C). The heads of the participants were stabilized on a chin rest during the RT
130 measurement to ensure that the eyes were directly in front of, and level with, the position of
131 the fixation point. The chin rest was located between the handlebars. Participants were asked
132 to focus on the fixation point binocularly throughout the RT measurement.

133 One RT-measurement block consisted of 60 trials. At the beginning of a block, all
134 LEDs were lit up for 3 s, serving as a warning that the block was about to begin. After 3 s, the
135 yellow LEDs were extinguished, while the fixation light remained illuminated throughout the
136 remainder of the block. After a variable interval (2.5 to 3.5 s, with a step of 0.25 s), one of the
137 yellow LEDs was illuminated. Each trial then consisted of a yellow LED for 100 ms followed
138 by the variable interval. For analysis, RTs in each condition were combined because a
139 previous study has indicated that differences in premotor time are small within the same
140 visual field [3].

141

142 *2.4. Electromyogram measurement*

143 Surface electromyograms (EMGs) were recorded over the extensor pollicis longus
144 muscle of the right forearm (Bagnoli, Delsys Inc., Boston, MA). This measurement allowed
145 us to determine the onset of EMG activity without interference from muscle contraction
146 needed for grasping of the handlebars. The analog output of the EMG was recorded at a
147 sampling rate of 1 kHz using a PowerLab analog-to-digital converter (ML880/P
148 PowerLab16/30, A/D instruments Japan, Tokyo, Japan). In the present study, RT was divided
149 into premotor and motor components (premotor time and motor time) based on the EMG
150 activity that reflected the motor response [7]. The onset of muscle contraction was
151 determined by computer software combined with visual inspection. The details of the
152 software used to determine contraction onset have been described elsewhere [5]. In the
153 present study, we defined premotor time as the portion of the RT lasting from stimulus onset
154 to onset of the motor response [3-5]. Motor time was the remaining portion of the RT, lasting
155 from the onset of the motor response until the button was released, which mainly reflect the
156 time required for muscle contraction [10, 11].

157

158 *2.5. Other measurements*

159 Before and immediately after exercise, capillary blood was collected from the right
160 earlobe to determine blood lactate concentration (Lactate Pro, Arkray, Kyoto, Japan). During
161 the experiment, we measured minute ventilation (\dot{V}_E) and $\dot{V}O_2$, and heart rate (HR) using a
162 heart-rate monitor (RS800CX, Polar, Finland). Ratings of perceived exertion (RPE; 6–20
163 Borg scale) [6] were recorded immediately after each RT measurement. An
164 electro-oculogram (EOG) was recorded at a sampling rate of 1 kHz to monitor overt eye
165 movements and eye blinking during the RT measurement.

166

167 *2.6. Data and statistical analysis*

168 We excluded some trials from analysis. First, we excluded error trials, defined as
169 those in which no response was made to the visual stimulus, a response was made during the
170 variable interval before stimulus onset, or the RT was less than 100 ms (anticipation). Second,
171 we excluded trials in which overt eye movements or eye blinking was detected. After these
172 trials were excluded, premotor and motor times were averaged for each participant. \dot{V}_E , $\dot{V}O_2$,
173 and HR during the RT measurement were also averaged. For the premotor time, motor time,
174 error trials, \dot{V}_E , $\dot{V}O_2$, HR, and RPE, we performed a repeated-measures ANOVA with
175 Condition (central or peripheral) and Exercise (rest, moderate, or strenuous) as
176 within-participant variables. For blood lactate concentration, we performed an ANOVA with
177 Condition and Time (pre or post) as within-variables. The degree of freedom was corrected
178 using the Huynh Feldt Epsilon when the assumption of sphericity was violated. We
179 conducted Tukey's multiple comparisons or t-tests, where appropriate. All data are expressed
180 as the mean \pm SD. The level of significance was set at $P < 0.05$.

181

182 3. Results

183

184 3.1. Physiological parameters and RPE

185 Analysis of the physiological measurements and RPE are shown in Table 1. We
186 observed significant main effects of Exercise on \dot{V}_E [F(1,15,14.95) = 330.25, $P < 0.001$, $\eta_p^2 =$
187 0.96], $\dot{V}O_2$ [F(1,43,18.63) = 1930.98., $P < 0.001$, $\eta_p^2 = 0.99$], HR [F(2,26) = 1849.55, $P <$
188 0.001, $\eta_p^2 = 0.99$], and RPE [F(2,26) = 1304.65, $P < 0.001$, $\eta_p^2 = 0.99$]. We also observed a
189 significant main effect of Time on blood lactate concentration [F(1,13) = 207.31, $P < 0.001$,
190 $\eta_p^2 = 0.94$]. We did not observe main effects of Condition on \dot{V}_E [F(1,13) = 1.32, $P = 0.27$,
191 $\eta_p^2 = 0.09$], $\dot{V}O_2$ [F(1,13) = 0.24, $P = 0.64$, $\eta_p^2 = 0.02$], HR [F(1,13) = 1.02, $P = 0.33$, $\eta_p^2 =$
192 0.07], RPE [F(1,13) = 0.10, $P = 0.76$, $\eta_p^2 = 0.01$], and blood lactate concentration [F(1,13) =

193 0.49, $P = 0.50$, $\eta_p^2 = 0.04$]. No interactions were found between Exercise and Condition on
 194 $\dot{V}E$ [$F(1,21,15.73) = 1.41$, $P = 0.26$, $\eta_p^2 = 0.10$], $\dot{V}O_2$ [$F(1,23,15.99) = 0.84$, $P = 0.40$, $\eta_p^2 =$
 195 0.06], HR [$F(2,26) = 0.89$, $P = 0.42$, $\eta_p^2 = 0.06$], and RPE [$F(2,26) = 1.29$, $P = 0.29$, $\eta_p^2 =$
 196 0.09], and between Time and Condition on blood lactate concentration [$F(1,13) = 0.12$, $P =$
 197 0.73 , $\eta_p^2 = 0.01$]. Hence, we combined data from both conditions for further analysis. Post
 198 hoc multiple comparisons indicated that $\dot{V}E$, $\dot{V}O_2$, HR, and RPE increased during exercise
 199 with the workload (all $P_s < 0.001$). Collectively, physiological parameters and RPE increased
 200 progressively with exercise, regardless of where the visual stimuli were presented (centrally
 201 or peripherally).

202

203 *Insert Table 1 about here*

204

205 *3.2. Premotor time and motor time*

206 Figure 2A shows the average premotor time at rest and during moderate and
 207 strenuous exercise. ANOVA revealed a significant main effect of Condition [$F(1,13) = 31.19$,
 208 $P < 0.001$, $\eta_p^2 = 0.71$], indicating that when visual stimuli were in the periphery, motor onset
 209 began later than when they were located centrally. We also found a significant interaction
 210 between Condition and Exercise [$F(2,26) = 4.19$, $P = 0.03$, $\eta_p^2 = 0.24$], indicating that
 211 changes in premotor time in response to exercise differed between the Central and Peripheral
 212 conditions. While premotor time did not change depending on the level of exercise during the
 213 Central condition, it increased with exercise in the Peripheral condition. Specifically,
 214 post-hoc multiple comparisons showed that premotor time was significantly longer during
 215 moderate exercise ($P = 0.03$) and strenuous exercise ($P < 0.001$) than at rest, and longer
 216 during strenuous exercise than during moderate exercise ($P = 0.03$). Figure 2B shows the
 217 average motor time at rest and during exercise. ANOVA revealed that motor time was not

218 affected by Condition [$F(1,13) = 0.22, P = 0.65, \eta_p^2 = 0.02$] or Exercise [$F(1.31,16.99) = 1.11,$
219 $P = 0.33, \eta_p^2 = 0.08$]. Error trials accounted for 3.6% of all trials. Exercise [$F(1,13) = 0.47, P$
220 $= 0.50, \eta_p^2 = 0.04$] or Condition [$F(2,26) = 1.90, P = 0.17, \eta_p^2 = 0.13$] did not affect the
221 number of error trials.

222

223 *Insert Figure 2 about here*

224

225 **4. Discussion**

226

227 The present study tested the hypothesis that slowed response to peripheral visual
228 stimuli during strenuous exercise can be attributed to impaired visual perception. We
229 observed that while premotor time for peripheral visual stimuli increased during moderate
230 and strenuous exercise, premotor time for central visual stimuli did not. These results
231 demonstrate that extended premotor time for peripheral visual stimuli was not the result of an
232 impaired neural network for motor responses, but was rather related to impaired peripheral
233 visual perception. Therefore, the conflict appears to be resolved, with impaired visual
234 perception being the major contributor to the effect. **In the present study, participants**
235 **responded to visual stimuli by releasing the button with the right thumb. The motor response**
236 **was a simple movement, and we do not assume that complex neural network was recruited.**
237 **Accordingly, it is no wonder that neural network for motor responses was not affected by**
238 **strenuous exercise.**

239 In the present study, we did not find differences between the Central and Peripheral
240 conditions in the physiological parameters or RPE values during exercise. This means that the
241 physical demands on the participants were practically identical between the two conditions.
242 We can therefore exclude the possibility that the difference in premotor time between

243 conditions was the result of differing physical demands. Furthermore, motor time did not
244 change during exercise in either the Central or Peripheral condition. These results
245 demonstrate that exercise did not affect the muscle contractions that were required for
246 responding to the visual stimuli.

247 In a previous study, we separately examined the effects of moderate exercise on
248 premotor time using either central or peripheral visual stimuli [2]. The results indicated that
249 premotor time to peripheral visual stimuli increased during moderate exercise, while
250 premotor time to central visual stimuli did not change. These findings were corroborated by
251 the present results showing that premotor time to peripheral visual stimuli increased during
252 moderate exercise. In a follow-up study, we investigated the effects of strenuous exercise on
253 premotor time under the condition that visual stimuli were randomly presented in a large area
254 of the central and peripheral visual fields with equal probability [3]. Then, we observed that
255 premotor time increased for both central and peripheral visual stimuli. However, because the
256 visual stimuli in that study were presented in a large area of the central and peripheral visual
257 fields, we could not be sure that the increased premotor time to peripheral visual stimuli
258 during strenuous exercise was exclusively because of impairments in peripheral visual
259 perception. To clarify this, here we used a block design to separately test how centrally and
260 peripherally presented visual stimuli affect premotor time during exercise.

261 We observed that premotor time for peripheral visual stimuli significantly increased
262 during strenuous exercise. Because the manual response was the same for both conditions, we
263 reasoned that if strenuous exercise only impairs peripheral visual perception, premotor time
264 for central visual stimuli would not increase during strenuous exercise. Indeed, premotor time
265 for central visual stimuli was not affected during strenuous exercise. Therefore, the present
266 results suggest that increases in premotor time to peripheral visual stimuli were not likely the
267 result of an impaired motor response. Rather, they likely resulted from impaired peripheral

268 visual perception. At the current stage, there is no theory to account for the present findings
269 sufficiently. However, in the Peripheral condition, participants probably oriented visual
270 attention to a large area of the visual field. Because higher cortical areas, including the
271 prefrontal and parietal cortex, are involved in the control of visual attention [8, 15], the
272 present results support the notion that strenuous exercise may impair the ability to orient
273 visual attention to a large area of the visual field [1]. Nevertheless, further investigation is
274 necessary to understand how strenuous exercise impairs peripheral visual perception. In
275 particular, the effects of acute exercise on early visual processing stages (e.g. retina) should
276 be investigated.

277 Kahneman [13] claimed that increased arousal causes narrowing of attentional focus,
278 with a progressive elimination of input from the more peripheral aspects of the environment.
279 In his proposal, the term “peripheral” does not mean peripheral vision *per se*, but refers to
280 events that are relatively improbable because most events are likely to occur in the central
281 visual field [16]. In the present study, participants were aware that visual stimuli would be
282 flashed in the periphery. However, premotor time increased during strenuous exercise only to
283 the peripheral visual stimuli. Our results are in line with Kahneman’s proposal; the increase
284 in arousal level induced by strenuous exercise led attentional focus to become narrow, which
285 impaired the ability to detect peripheral visual stimuli. Thus, apart from physiological
286 mechanisms, it is noteworthy that the present findings are compatible with this psychological
287 concept.

288 Until now, little has been known about how acute exercise affects peripheral visual
289 perception. Different findings may arise when different experimental conditions are
290 employed (e.g. physical fitness of participants, type of perceptual task, and exercise intensity
291 and duration). Therefore, it may be premature to draw a general conclusion that peripheral
292 visual perception is impaired during strenuous exercise. However, at this stage, our

293 behavioral data suggest that this is the case. In future studies, neuroimaging may provide
294 evidence that clarifies the effects of strenuous exercise on central and peripheral visual
295 perception. Finally, in the present study, we assessed peripheral visual perception exclusively
296 from the same horizontal plane. To further understand the effects of acute exercise on human
297 peripheral visual perception, peripheral visual perception needs to be assessed from a broader
298 range of the visual field including upper and lower visual fields.

299

300 **Conclusion**

301 The present study investigated whether slowed response to peripheral visual stimuli
302 during strenuous exercise results from impaired visual perception. The results demonstrated
303 that increases in premotor time for peripheral visual stimuli could not be explained by an
304 impaired neural network for motor responses, but could be explained by impaired peripheral
305 visual perception. Hence, we conclude that slowed response to peripheral visual stimuli
306 during strenuous exercise is primarily due to impaired peripheral visual perception.

307

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311 are no conflicts of interest.

312

313 **References**

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363 dynamic exercise in humans. *J Physiol* 1997;503 (Pt 2):277–83.

364

365 Figure Legends

366

367 Figure 1 (A) Illustration of the experimental protocol. Dashed lines show the duration of the
368 RT measurements (3 min). Downward arrows indicate the timing of each measurement. (B)
369 Location of the fixation point and visual stimuli (top view). Visual stimuli were positioned
370 horizontally at 2°, 5°, 30°, and 50° either to the right or left of the midpoint between the eyes
371 with an equidistance of 58 cm. (C) Simplified horizontal views from the participants. Dashed
372 ovals indicate areas of visual attention to which the participants were presumably oriented in
373 each condition. Note that shape, size, and angle of the stimuli were different from the actual
374 ones for clarification.

375

376 Figure 2 (A) Premotor time at rest and during moderate and strenuous exercise. (B) Motor
377 time at rest and during moderate and strenuous exercise. White bars represent the Central
378 condition. Black bars represent the Peripheral condition. # $P < 0.05$, ### $P < 0.001$, vs. Rest in
379 the Peripheral condition, § $P < 0.05$, vs. Moderate in the Peripheral condition.

380

Table 1. Results of physiological data and RPE.

Variable	Condition	Exercise workload			
		Rest	Moderate	Strenuous	After
\dot{V}_E , L/min	Central	9.5 ± 1.6	47.5 ± 6.8 *	84.8 ± 13.3 * †	
	Peripheral	8.9 ± 2.0	47.2 ± 8.4 *	81.7 ± 18.0 * †	
$\dot{V}O_2$, ml/min/kg	Central	4.6 ± 0.9	26.9 ± 3.1 *	40.1 ± 4.2 * †	
	Peripheral	4.6 ± 0.9	26.9 ± 2.1 *	39.1 ± 3.2 * †	
HR	Central	67 ± 11	135 ± 11 *	174 ± 12 * †	
	Peripheral	69 ± 10	137 ± 8 *	174 ± 9 * †	
RPE	Central	6.6 ± 0.9	12.3 ± 1.1 *	16.5 ± 1.5 * †	
	Peripheral	6.3 ± 0.5	12.6 ± 1.2 *	16.8 ± 0.9 * †	
Blood lactate concentration, mmol/l	Central	1.0 ± 0.2			6.6 ± 1.5 *
	Peripheral	1.1 ± 0.3			6.8 ± 1.7 *

Values are mean ± SD; * $p < 0.001$, vs. Rest; † $p < 0.001$ vs. Moderate.

RPE, Ratings of Perceived Exertion; \dot{V}_E , minute ventilation; $\dot{V}O_2$, oxygen uptake; HR, heart rate.

Figure 1
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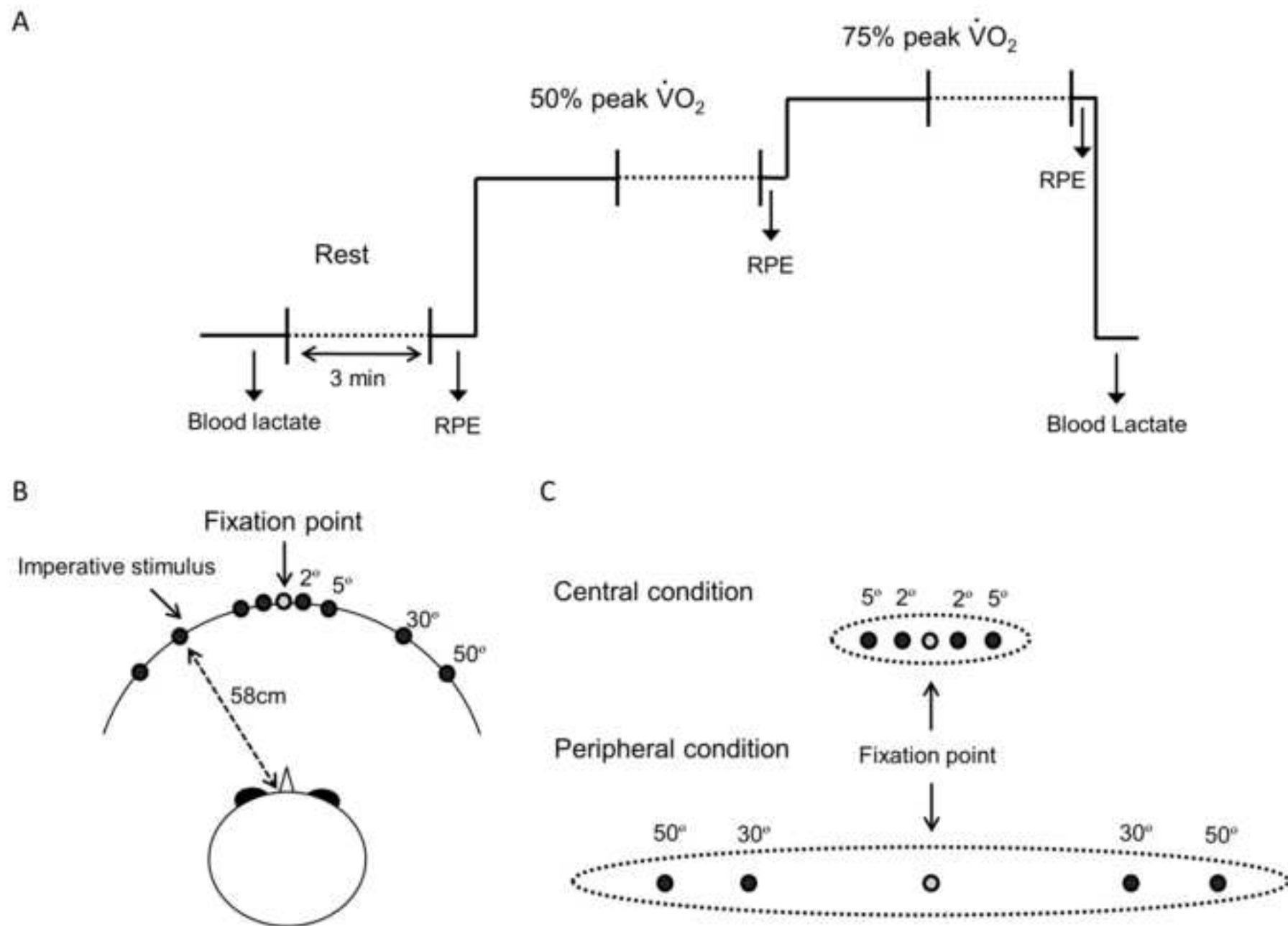


Figure 2
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