Influence of Exercise Intensity on Cognitive Processing and Arousal Level in the Central Nervous System

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Abstract

KAMIJO K., NISHIHIRA Y., HIGASHIURA T., HATTA A., KANEDA T., KIM S.R., KUROIWA K. and KIM B.J., Influence of Exercise Intensity on Cognitive Processing and Arousal Level in the Central Nervous System. Adv. Exerc. Sports Physiol., Vol.12, No.1 pp.1-7, 2006. The purpose of the present study was to investigate the influence of exercise intensity on cognitive processing and arousal level in the central nervous system (CNS) using P3 and contingent negative variation (CNV) event - related brain potentials (ERP). Fifteen participants (25.40 ± 0.77 yrs) performed a go/no - go reaction time task in a control condition, and again after low - (rating of perceived exertion: RPE: 11), medium - (RPE: 13), and high - intensity (RPE: 15) pedaling exercises. The exercise intensity was established using Borg's RPE scale. Electromyographic reaction time (EMG - RT) after medium - intensity exercise was faster than in a control condition and after low - and high - intensity exercises, and after low - intensity exercise was faster than in a control condition. In addition, the P3 amplitude after medium - intensity exercise was larger than in a control condition and after low - and high - intensity exercises, and after low - intensity exercise was larger than in a control condition. However, EMG - RT and P3 amplitude did not change after high - intensity exercise. It is suggested that cognitive processing in the CNS is facilitated by low - to medium - intensity exercise (RPE: 11 - 13, about 60 - 70 % of maximum heart rate: HRmax) but not by high - intensity exercise. In other words, exercise initially facilitates cognitive processing in the CNS; however as exercise intensity increases, the facilitative effects of exercise are abolished. Furthermore, early CNV amplitude was largest after medium - intensity exercise. These results suggested that the fastest EMG - RT and the largest P3 amplitude after medium - intensity exercise

were caused by the optimal arousal level. The present study supported our previous findings that P3 and CNV amplitude show inverted - U shaped behavior with differences in exercise intensity.

Keywords: exercise intensity, cognitive processing, arousal level, P3, CNV

Introduction

The effects of exercise on the respiratory, circulatory, and muscular systems have been well reported. Increasing evidence has shown that regular participation in physical activity of moderate intensity is associated with health benefits (1). Moreover, the psychological effects of exercise on cognitive processing have also been well documented. Most of these studies investigating the effect of exercise on cognitive processing employed behavioral measures such as reaction time (RT) and accuracy of cognitive performance (26). Methods for investigating the relationship between exercise and cognitive processing has progressed rapidly because of advances in electrophysiological indices such as event - related brain potentials (ERP), and electroencephalographic (EEG) frequency components. Recent studies investigating the effect of exercise on ERP, particularly on the P3 components, have found some evidence for the relationship between exercise - induced arousal and cognitive performance improvement (6, 8, 16, 19, 21, 29). P3 is known to be an endogenous component. Theoretically, P3 is believed to be an index of brain activity required in the maintenance of working memory when the mental model of the stimulus environment is updated (5).

However, how exercise intensity and duration influences cognitive processing in the CNS remains unclear. Previously, we investigated the influence of exercise intensity on cognitive processing in the CNS using P3 (10). We observed that P3 amplitude increased after medium - inten-
sity pedaling exercise and decreased after high-intensity pedaling exercise. Additionally, we also investigated the influence of exercise intensity on arousal level using contingent negative variation (CNV) (9) because P3 is influenced by biological processes such as fluctuations in the arousal state of participants (23). CNV is associated with psychophysiological events including expectancy, motivation, attention, and arousal. In particular, the relationship between early CNV in the frontal region and arousal level has been reported (7, 25). The changes in CNV amplitude of our previous study suggested that arousal level was reduced after high-intensity exercise and reached a near optimal level after medium-intensity exercise.

Although we suggested that differences in exercise intensity influenced cognitive processing and the arousal level in the CNS, the differences in exercise intensity used in the previous study were too large. In the high-intensity exercise, the participants performed pedaling exercises until volitional exhaustion was reached, and in the low-intensity exercise, only until the rating of perceived exertion (RPE) value was about 8 (very, very light). Therefore, we found it necessary to investigate the influence of exercise intensity on cognitive processing in the moderate-intensity range in order to clarify the optimal exercise intensity for cognitive processing in the CNS.

In the present study, exercise intensity was established using Borg’s RPE scale (2), because it provides exercise at all fitness levels with easily understood guidelines regarding exercise intensity (1). It has been found that a cardiorespiratory training effect and the threshold for blood lactate accumulation are achieved at a rating of “somewhat hard” to “hard”, which approximates a rating of 12 to 16 on the category scale (1). Hence, we defined each exercise intensity using RPE in the present study: low (~, medium -, and high - intensity correspond to 11 (fairly light), 13 (somewhat hard), and 15 (hard), respectively. In addition, Tuson et al. (27) reported that changes in positive affect are associated with participants’ subjective ratings of perceived exercise intensity, but not be related to objective exercise workload. It is suggested that P3 is more amenable to subjective exercise intensity (i.e., RPE) than objective exercise intensity (i.e., heart rate or oxygen uptake), because P3 is endogenous component influenced by various psychological factors such as decision confidence (24), motivation (3) and emotion (18).

Therefore, the purpose of the present study was to investigate the influence of exercise intensity on cognitive processing and arousal level using P3 and CNV in the moderate-intensity range (11 - 15 in RPE value) in order to clarify the optimal exercise intensity.

Methods

1. Participants

Fifteen healthy males (25.40 ± 0.77 yrs) participated in this experiment. All had medical histories free of significant neurological problems, and none were taking medication known to affect brain activity. The participants gave informed consent to participate in the experiment. The appropriate committee at the University of Tsukuba approved the experimental protocols.

2. Procedure

This experiment consisted of a control condition and three exercise conditions (low -, medium -, and high - intensities). Each condition was conducted on a different day, with an interval of at least 4 days between tests to prevent participants from becoming habituated to the go/no-go RT task. The order of conditions was randomized among the participants. In the control condition, participants were seated comfortably in a reclining chair during the experiment. They were instructed to look at a fixed point 1 meter in front of them. ERP (P3 and CNV) were evoked using a go/no-go RT task. In the exercise conditions, the participants exercised at each of the three intensities using a bicycle ergometer. Immediately after exercise, the participants performed the same go/no-go RT task as in the control condition. The go/no-go RT task started less than 3 min after exercise. A small amount of blood was taken from the participants’ fingertips, and blood lactate was measured before and after exercise using Lactate Pro (ARKRAY), a small blood lactate testing device. The increase in values of blood lactates between pre- and post-exercise was defined as Δ lactate.

3. Exercise

Before the experiment, participants performed a graded exercise test (GXT) using a bicycle ergometer to measure correlation of heart rate (HR) and RPE. During the GXT, the work rate (WR) increased by 15 W per min. The HR and RPE were recorded every min. RPE values were recorded using the Borg scale (2). The pedaling rate was kept at 60 revolutions per min. Participants pedaled for 2 min with no load as a warm-up. After warm-up, the participants pedaled until volitional exhaustion was reached according to the above-mentioned method. Participants were verbally encouraged to achieve their maximal level.

Target HRs equivalent to 11 (fairly light: low-intensity exercise), 13 (somewhat hard: medium-intensity exercise), and 15 (hard: high-intensity exercise) in RPE value were calculated from the regression lines of RPE versus HR in the GXT, respectively. The brake pressure was adjusted mechanically to the target HR in each exercise intensity condition. After warm-up with no load for 2 min, the participants performed exercise at each load corresponding to the target HR for 20 min. The pedaling rate was kept at 60 revolutions per min.
4. Go/no - go RT task

The go/no - go RT task consisted of a warning stimulus (S1) followed 2 s later by an imperative stimulus (S2). A binaural 2000 Hz tone (5 ms rise/fall, 50 ms plateau, 60 dB SPL) was used for S1. For S2, green and red LEDs (duration 200 ms) at the fixation point appeared randomly, with both colors appearing with the same probability. Participants were instructed to press a button with their thumb as fast as possible whenever the green LED was presented, but were told not to respond to the red LED. They performed the go/no - go RT task in about 80 trials (go : no - go = 40 : 40) for all conditions. The inter-trial interval was 10 s, and the task duration was about 13 min.

5. Recording conditions

EEG activity was recorded with Ag - AgCl electrodes at Fz, Cz, Pz, C3, and C4 according to the international 10 - 20 system, with each electrode referenced to linked earlobes. All electrodes had a resistance of less than 5 k ohm. It was confirmed that impedances did not vary after exercise. To monitor possible artifacts due to eye movement, an electrooculogram was recorded using electrodes placed above and below the right eye. The time constant for P3 was set at 0.3 s and a high - cut filter of 120Hz, and the time constant for CNV was set at 5 s. An electromyographic (EMG) was recorded using a pair of surface electrodes on the right hand flexor pollicis brevis muscle. EMG activity was amplified with a time constant of 0.03 s and a high - cut filter of 120 Hz.

EEG data were converted from 3000 ms pre - S2 to 1000 ms post - S2 at a sampling rate of 500 Hz. Trials with eye blinks, eye movements (rejection levels: ± 80 μV) and response errors were excluded from analysis. P3 was defined as the most positive peak that appeared in a post - S2 window of 250 to 500 ms. P3 amplitude was measured relative to a 100 ms pre - S2 baseline. P3 latency was defined as the time from the S2 onset to the peak point. CNV amplitude was measured relative to a 500 ms pre - S1 baseline. The mean amplitude during the 500 to 1000 ms after S1 (early CNV) was calculated with an averaged CNV.

The EMG data were converted at a sampling rate of 500 Hz, and EMG - RT was measured as the time from S2 onset to a sharp increase in EMG bursts.

6. Statistical analysis

The Δ lactate and EMG - RT data were analyzed using one - factor (exercise intensity) analysis of variance (ANOVA) with repeated measures. P3 and CNV were analyzed using two - factor (exercise intensity × electrode site) ANOVA with repeated measures. The reported significances for the F values were those obtained after Greenhouse - Geisser correction when appropriate, and then a correction coefficient epsilon was given. When the main effects were identified, a Tukey's HSD post hoc multiple - comparison test of significant difference was performed to identify the specific differences in factors contributing to the variance observed in the data. The significance level was set at $p < 0.05$.

Results

1. Exercise

Table 1 shows the average RPE, HR (%HRmax) and WR for 20 min in each exercise condition. These data at each level of exercise intensity were clearly different. The Δ lactate was $0.43 \pm 0.30$ mmol/l in low - intensity exercise, $1.90 \pm 0.40$ mmol/l in medium - intensity exercise, and $3.66 \pm 0.53$ mmol/l in the high - intensity exercise. The Δ lactate was analyzed using one - factor (exercise intensity) ANOVA. The main effect was significant [$F(2, 28) = 47.39$, $p < 0.001$]. The Tukey's HSD post hoc analysis indicated that the Δ lactate in high - intensity exercise was significantly larger than in low - and medium - intensity exercise, and that the Δ lactate in medium - intensity exercise was significantly larger than in low - intensity exercise.

These results indicate that each exercise used in the study differed in intensity. The average RPE for 20 min was smaller than the target RPE (low: 11, medium: 13, high: 15) because the RPE value for a few min after the commencement of exercise was low. We considered the target exercise intensity mostly maintainable, although the average RPE for 20 min was slightly small.

<table>
<thead>
<tr>
<th></th>
<th>low</th>
<th>medium</th>
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<tbody>
<tr>
<td>RPE value</td>
<td>10.07 ± 0.29</td>
<td>12.21 ± 0.22</td>
<td>14.17 ± 0.22</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>112.48 ± 2.34</td>
<td>128.86 ± 2.60</td>
<td>145.36 ± 3.14</td>
</tr>
<tr>
<td>(% HRmax)</td>
<td>(60.20 ± 0.92 %)</td>
<td>(68.98 ± 1.04 %)</td>
<td>(77.83 ± 1.37 %)</td>
</tr>
<tr>
<td>WR (W)</td>
<td>91.09 ± 5.93</td>
<td>115.97 ± 4.62</td>
<td>139.36 ± 4.62</td>
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</table>

Values are mean ± SE.
2. EMG - RT

EMG - RT was 219.62 ± 9.74 ms in the control condition, 202.03 ± 7.91 ms after low - intensity exercise, 186.08 ± 6.40 ms after medium - intensity exercise, and 213.39 ± 9.53 ms after high - intensity exercise. EMG - RT was analyzed using one - factor (exercise intensity) ANOVA. The main effect was significant \([F (3, 42) = 18.70, p<0.001]\). The Tukey’s HSD post hoc analysis indicated that EMG - RT after medium - intensity exercise was shorter than in the control condition and after low - and high - intensity exercise. In addition, EMG - RT after low - intensity exercise was shorter than in the control condition.

3. P3

Fig. 1 shows the grand averaged P3 waveforms for all conditions. On first inspection, it appeared that P3 amplitude increased after exercise, and the difference between the control condition and medium - intensity exercise was especially remarkable. P3 amplitudes were analyzed using two - factor (exercise intensity × electrode site) ANOVA. The main effects of exercise intensity and electrode site on P3 amplitude were significant \([F (3, 42) = 16.63, p<0.001]; F (4, 56) = 50.82, p<0.001, \text{ respectively}\). There was no significant interaction between the two factors. The Tukey’s HSD post hoc analysis for electrode site indicated that P3 amplitude reached its maximum at the centro - parietal region. The P3 amplitude after medium - intensity exercise was significantly larger than in the control condition and after high - intensity exercise at all electrode sites, and after low - intensity exercise at Cz, C3 and C4. In addition, the P3 amplitude after low - intensity exercise was significantly larger than in the control condition at Cz. (Table 2).

P3 latency was analyzed using two - factor (exercise intensity × electrode site) ANOVA. The main effect was significant for electrode sites but not for exercise intensity. There was no significant interaction between the two factors.

4. CNV

Fig. 2 shows the grand averaged CNV waveforms for all conditions. On first inspection, it appeared that the CNV amplitude increased after medium - intensity exercise, as had the P3 amplitude. Early CNV amplitude was analyzed using two - factor (exercise intensity × electrode site) ANOVA. The main effects of exercise intensity and electrode site on early CNV amplitude were significant \([F (3, 42) = 10.70, p<0.001]; F (4, 56) = 12.07, p<0.001, \text{ respectively}\). There was significant interaction between the two factors \([F (12, 168) = 2.19, p = 0.014]\). The Tukey’s HSD post hoc analysis of electrode sites indicated early CNV amplitude reached its maximum at the front - central region. The early CNV amplitude after medium - intensity exercise was significantly larger than in the control condition at all electrode sites, and significantly larger than after

![Fig. 1](image1.png) Grand averaged P3 waveforms (n=15) from all electrode sites (Fz, Cz, Pz, C3, and C4) for all conditions (control condition and after low -, medium - and high - intensity exercise).
low - and high - intensity exercise at Fz. After low - intensity exercise was significantly larger than in the control condition at C4 (Table 3).

Discussion

Previously, we indicated differences in exercise intensity influenced cognitive processing and arousal level in the CNS (9, 10). However, the differences in exercise intensity used in the previous study were too large. In the present study, we investigated the influence of exercise intensity on cognitive processing using P3 and CNV in the moderate - intensity range (11 - 15 in RPE value) in order to clarify the optimal exercise intensity.

P3 amplitude after medium - intensity exercise was significantly larger than in the control condition and after low - and high - intensity exercise, and after low - intensity exercise was larger than in the control condition. It is thought that P3 amplitude elevates from low to medium - intensity exercise (RPE: 11 - 13), but when exercise intensity remains elevated above that level, P3 amplitude starts to decrease. P3 amplitude is considered to be closely related to the intensity of processing (13) and is especially proportional to the amount of attentional resources given to a particular task (12, 14). These findings suggested that more attention was invested in a task after low - and medium - intensity exercises. According to Tomporowski (26), exercise may initially facilitate the attentional process by directly affecting CNS; however, as exercise intensity or duration increases, the facilitative effects of exercise may be cancelled by the debilitating effects of muscular fatigue. In addition, EMG - RT after low - and medium - intensity exercises were shorter than in the control condition.

Kida et al. (11) investigated the relationship between ERP and the variation of RT, suggesting that larger P3 amplitude in fast - RT trials implied that when larger amounts of attentional resources were allocated to a given task, RT was shortened to a great extent. The P3 amplitude was larger when the RT was fast after low - and medium - intensity exercise, implying that when more attentional resources were allocated to the given task, the response speed was faster.

Early CNV amplitude after medium - intensity exercise was significantly larger than in the control condition. The relationship between early CNV in the frontal region and arousal level has been well reported (7, 25). It has also been reported that the mechanism of CNV generation involves the ascending reticular formation system, which is strongly related to arousal level (17). It is suggested that CNV amplitude and arousal level were in an inverted - U relationship (7, 25). Furthermore, Werre (28) supported the assumption of the inverted - U; he proposed that the maximum value shown by CNV corresponds to the optimal arousal level. That is, participants reached a state near the optimal arousal level after medium - intensity exercise.

In the present study, P3 amplitude and early CNV amplitude were largest and EMG - RT was fastest after medium - intensity exercise. Magniè et al. (16) and Yagi et al. (29) showed that P3 amplitude varies with acute exercise, suggesting that arousal level is an important influencing factor. The arousal concept was used to account for the observation that task performance could often be characterized as an inverted - U shaped function of arousal (30). As physical arousal increases, performance improves to an op-
Table 2  P3 amplitude (μV) at each electrode site in all conditions.

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>low</th>
<th>medium</th>
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<tbody>
<tr>
<td>Fz</td>
<td>10.56 ± 1.73</td>
<td>12.33 ± 1.32</td>
<td>14.74 ± 1.50*</td>
<td>11.93 ± 1.30*</td>
</tr>
<tr>
<td>Cz</td>
<td>20.32 ± 1.89</td>
<td>23.37 ± 2.09*</td>
<td>26.52 ± 2.34*</td>
<td>21.36 ± 2.04*</td>
</tr>
<tr>
<td>Pz</td>
<td>20.66 ± 1.89</td>
<td>22.87 ± 1.57*</td>
<td>24.85 ± 2.11*</td>
<td>20.19 ± 1.81*</td>
</tr>
<tr>
<td>C3</td>
<td>15.45 ± 1.67</td>
<td>16.95 ± 1.65</td>
<td>19.55 ± 1.70*</td>
<td>15.54 ± 1.36*</td>
</tr>
<tr>
<td>C4</td>
<td>15.59 ± 1.52</td>
<td>17.73 ± 1.49</td>
<td>20.85 ± 2.03*</td>
<td>15.51 ± 1.26*</td>
</tr>
</tbody>
</table>

Values are means ± SE. Significant difference by Tukey’s HSD post hoc analysis for exercise, *p<0.05: control vs. low, °p<0.05: control vs. medium, °°p<0.05: low vs. medium, °°°p<0.05: medium vs. high.

Table 3  Early CNV amplitude (μV) at each electrode site in all conditions.

<table>
<thead>
<tr>
<th></th>
<th>control</th>
<th>low</th>
<th>medium</th>
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<tbody>
<tr>
<td>Fz</td>
<td>-1.57 ± 0.63</td>
<td>-3.56 ± 0.57</td>
<td>-6.16 ± 0.78*</td>
<td>-3.58 ± 0.44*</td>
</tr>
<tr>
<td>Cz</td>
<td>-2.84 ± 0.63</td>
<td>-4.37 ± 0.40*</td>
<td>-5.84 ± 0.64*</td>
<td>-4.38 ± 0.58</td>
</tr>
<tr>
<td>Pz</td>
<td>-0.78 ± 0.55</td>
<td>-1.54 ± 0.53</td>
<td>-3.23 ± 0.45*</td>
<td>-1.61 ± 0.64</td>
</tr>
<tr>
<td>C3</td>
<td>-1.31 ± 0.42</td>
<td>-2.61 ± 0.33</td>
<td>-4.15 ± 0.59*</td>
<td>-3.57 ± 0.62*</td>
</tr>
<tr>
<td>C4</td>
<td>-1.16 ± 0.40</td>
<td>-3.23 ± 0.51*</td>
<td>-3.86 ± 0.44*</td>
<td>-2.73 ± 0.59</td>
</tr>
</tbody>
</table>

Values are means ± SE. Significant difference by Tukey’s HSD post hoc analysis for exercise, *p<0.05: control vs. low, °p<0.05: control vs. medium, °°p<0.05: control vs. high, °°°p<0.05: low vs. medium, °°°°p<0.05: medium vs. high.

timal point, and then deteriorates with further increases in physical arousal (26). Moreover, Polich and Kok (23) indicated that P3 was influenced by biological processes such as fluctuations in the arousal state of participants. These findings suggested that the arousal level was affected by changes in exercise intensity, and it may be that P3 amplitude is influenced by those changes.

The studies compared pre-exercise with post-exercise EEG reported significant increases in α activity after aerobic exercise (15). Increased α activity reflects a state of decreased cortical activation indicative of fatigue, relaxation, or decreased anxiety (22). In addition, Nielsen et al. (20) investigated whether progressive hyperthermia and ultimately fatigue during exercise in hot environment are in part related to altered brain activity, indicating that during exercise in the heat, the core temperature rises and that there is a concomitant shift in the EEG power distribution, a decrease in β and a steady increase in the α/β index; an elevated α/β index reflects suppressed arousal. They concluded that increases in the α/β index were strongly correlated to increases in oesophageal temperature. According to these findings, it might be that arousal level reduced after higher intensity exercise because of increases in body temperature, thereby facilitative effects on cognitive function caused by acute exercise was cancelled after high-intensity exercise.

Recent studies investigating the effect of exercise on ERP have found some evidence for the relationship between exercise-induced arousal and cognitive performance improvement (6, 8, 16, 19, 21, 29). However, the often contradictory findings of experimental research have led several authors to identify four methodological factors to control in such studies: (i) the physical fitness of participants, (ii) the intensity and duration of physical exercise, (iii) the nature of the psychological task, and (iv) the time at which the psychological task was administered to the participants (4). The present study only examined the second factor, and it is evident that additional studies incorporating the above-mentioned methodological factors are necessary. The present study indicated that differences in exercise intensity influenced cognitive processing in the moderate-intensity range. In conclusion, we suggested that cognitive processing in the CNS is facilitated by low-to-medium-intensity exercise (RPE: 11 – 13, about 60 – 70% HRmax) but the facilitative effects of exercise are cancelled after high-intensity exercise (RPE: 15, about 80% HRmax).

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References


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