The effect of high and low exercise intensity periods on a simple memory recognition test

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Abstract

Purpose: The purpose of this study was to investigate the effect of variable intensities on a simple memory recognition task during exercise.

Methods: Twenty active participants took part in initial testing, a familiarization trial and then four 60 min cycling interventions in a randomized order. Interventions consisted of no exercise (control), constant exercise at 90% ventilatory threshold (constant) and 2 trials that initially mimicked the constant trial, but then included periods of high (~90% VO2peak) and low intensities (~50% VO2peak). Cardiorespiratory measures and capillary blood samples were taken throughout. A short tablet-based cognitive task was completed prior to and during (50 and 55 min into exercise) each intervention.

Results: The exercise conditions facilitated response time (p = 0.009), although the extent of this effect was not as strong in the variable exercise conditions (p = 0.011–0.089). High intensity exercise periods resulted in some cognitive regression back towards control trial performance. Elevations in cardiorespiratory measures and periods of hypocapnia could not explain changes in cognitive performance.

Conclusion: Changes in cognitive performance with variations in exercise intensity are likely to have implications for sport and occupational settings. The timing of cognitive tests to exercise intensity changes as well as use of short cognitive assessments will be important for future work. © 2016 Production and hosting by Elsevier B.V. on behalf of Shanghai University of Sport. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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1. Introduction

In sporting environments, as well as in some occupational settings, physical demands are dynamic and can reach levels high enough to interfere with decision making. Studies of exercise and cognition, to date, have focused on either constant power outputs or incremental protocols which have revealed an inverted-U relationship between exercise intensity and cognitive performance during exercise.1 The inverted-U describes a relationship where cognitive performance, generally decision making speed, is most facilitated at moderate exercise intensities, with reduced performance at both the lowest and highest exercise intensities. Optimal cognitive function at moderate exercise intensities, just below and around ventilatory threshold (VT), may be attributable to physiological changes as this exercise intensity corresponds with peak oxygenation of the frontal lobe.2 Above this intensity there is also a reduction in cerebral blood flow.2,3 An alternate explanation is that, partly due to the brain’s limited resources, exercise disengages the higher order functions of the prefrontal cortex as predicted by the reticular-activating hypofrontality (RAH) theory.4 Activities which require intermittent changes in exercise intensity present a more complex situation as physiological changes that are likely to influence cognition can be short lived.

Intermittent exercise protocols investigating changes in cognition are limited. Two investigations utilizing intermittent protocols have tested cognition soon after the termination of the exercise protocol.5,6 These studies provide insight into how the overall strain of protocols incorporating varying intensities affects cognition but offer little on how cognition might change during the varying exercise demands. In a recent publication investigating soccer players it was found that a prolonged intermittent protocol resulted in reduced accuracy in a perceptual-cognitive task.7 The protocol employed demanded increases in exercise intensity although heart rate (HR) and blood lactate data suggest that these demands were not much higher than VT. It is also unclear if the cognitive tests in this study were...
undertaken during the exercise, or shortly after during brief breaks in the protocol. Thus there is considerable uncertainty about how varying exercise intensities effects cognitive performance.

As a result of the uncertainty surrounding cognition during intermittent exercise, we used an initial moderate intensity period followed by periods of low and high intensities to best simulate what could occur in a sporting or occupational setting. The baseline moderate intensity, 90% of an individual’s VT, is closely linked to optimal cognitive performance and cerebral blood flow\(^1\) and is a common intensity used in the literature.\(^6\)-\(^11\)

Low (−50% \(\text{VO}_{\text{peak}}\)) and high (−90% \(\text{VO}_{\text{peak}}\)) intensity periods were then utilized as these intensities would provide large physiological changes which are thought to limit the brain’s resources.\(^12\),\(^13\) These exercise intensities would also produce large changes in cardiopulmonary variables (\(\text{pCO}_2\), \(\text{pO}_2\), and cardiac output) that can influence cerebral blood flow.\(^14\) For the cognitive task we utilized a readily accessible, brief and easily administered task that could be undertaken whilst exercising. We have previously shown that this task can detect enhanced performance during moderate intensity steady-state aerobic exercise.\(^15\) We hypothesized that cognitive testing during the high intensity periods would result in impaired cognitive task performance and that this would be associated with cardiopulmonary variables.

2. Methods

2.1. Participants

Twenty healthy, active participants (10 males aged 26.6 ± 5.2 years; \(\text{VO}_{\text{peak}}\) 55.4 ± 9.7 mL/kg/min; and 10 females aged 24.6 ± 5.6 years, \(\text{VO}_{\text{peak}}\) 43.7 ± 6.1 mL/kg/min) provided informed consent for the project approved by the local university ethics committee (University of Canberra Committee for Human Ethics No.10–63). Participants were asked to refrain from heavy exercise and avoid high caffeine foods on the day prior to testing. Compliance was confirmed through the use of a short questionnaire.

2.2. Design

In the week following the initial test, participants cycled a 1 h familiarization trial at −90%VT. In subsequent visits, participants completed the 4 conditions in a randomized order, with 3–7 days between each condition, conducted at the same time of day. The conditions were no exercise ("control"), constant power at 90%VT ("constant") and 2 trials that were identical to the constant condition up to 40 min, and then included variable power outputs consisting of two 3 min periods of alternating heavy (−90% \(\text{VO}_{\text{peak}}\)) and light intensities (−50% \(\text{VO}_{\text{peak}}\)) before resuming the 90%VT power from the 52-min time point up until completing the 1 h trial (Fig. 1). The 2 variable trials had the heavy and light intensities presented in different orders so that we could test cognition at different exercise intensities (with accompanying different attentional demands) but at the same time point for different trials. During all trials a cognitive task was performed twice pre-condition (the mean of these being referred to as the baseline), and then at 50 and 55 min during exercise. This resulted in the 50 min cognitive performance test being performed during either a period of light ("low") or heavy ("high") intensity for the 2 variable trials which were accordingly named either the variable low or variable high exercise trials.

2.3. Methodology

2.3.1. Preliminary procedures

Participants were familiar with the cognitive task performance as they were previously involved in earlier published work.\(^15\) An initial maximal cycle test was used to assess \(\text{VO}_{\text{peak}}\) and VT. VT was assessed by 2 independent experienced researchers using 3 different methods as previously described.\(^16\) The maximal cycle test began with a 5 min warm-up between 50 and 75 W before power output was increased by 15–25 W every 2 min. The starting power output and stage progression were chosen based on sex and previous test results in our laboratory so that maximal exertion would be achieved between −12 and 15 min after completion of the warm-up.

2.3.2. Apparatus and display

The participant sat on a cycle ergometer (Lode Excalibur, Groningen, the Netherlands) with upright handlebars. A touch screen tablet computer (A4-sized) was placed in the middle of the handlebars (50–60 cm from the eyes depending on posture) at an angle of approximately 45° offering easy access and visual positioning. All testing was performed in an air conditioned laboratory (21.8 °C ± 1.1 °C, relative humidity 46.0% ± 11.4%).

2.3.3. Measures

Gas analysis (ParvoMedics TrueOne, Salt Lake City, UT, USA) and HR (Polar Electro, Kempele, Finland) were taken throughout the trials. Expired gas was collected with a Hans-Rudolph valve which was not reported to obstruct the cognitive task by participants. The gas analysis system was calibrated according to manufacturer instructions prior to each trial. A 2-point gas calibration and series of volume measurements using a fixed volume, but at different simulated ventilation...
rates, approach was taken. Capillary blood samples were taken from the fingertip prior to beginning each trial and then immediately after completing the cognitive tasks at 50 min. Samples were analyzed immediately for lactate, oxygen and carbon dioxide tensions (pO2 and pCO2) and pH using an iStat radiometer (CG4 cartridge; Abbott Point of Care, Princeton, NJ, USA). The iStat radiometer was calibrated prior to the initial trial measurement, and then again prior to the 50 min sample according to manufacturer instructions. These measures were taken to see if physiological variables likely to influence cerebral perfusion were altered under the different exercise conditions.

### 2.3.4. Cognitive task

The Speed Match task ([http://www.lumosity.com/brain-games/speed-games/speed-match](http://www.lumosity.com/brain-games/speed-games/speed-match), Lumos Labs Inc., San Francisco, CA, USA) was utilized in the present study and has previously been shown to display face validity.13 We previously reported coefficients of variation of 3.5% and 5.8% for accuracy and response time when undertaking this task with no exercise, and 4.5% and 6.7% during constant moderate intensity exercise. The task has similarities to the 1-back condition of the n-back task, in which participants must identify whether the presented stimulus is the same, or different, to the one presented one trial previously as quickly as possible. This particular task presents as a fairly basic memory recognition challenge in which there is a particular focus on pattern recognition (Fig. 2). At each cognitive task attempt participants were instructed: “This is the cognitive task again. Try to make your responses as accurate and fast as possible. Stay as accurate and fast as possible. Start when you are ready.”

Upon completion of the 45 s task, mean response time of all attempts was recorded along with the number of correct responses and accuracy (number of correct responses divided by total number of responses offered).

### 2.4. Statistical analysis

Cognitive performance measures were expressed relative to the individual’s baseline results on the day of each trial (as a percent of the baseline). This allowed for comparisons of how the intervention altered the cognitive performance within each trial. A repeated measures, for 2 within-subject factors, analysis of variance was conducted to assess the impact of 4 different intervention trials (control, constant exercise, variable low, and variable high exercise conditions) on participant’s cognitive performance across 2 time points (50 and 55 min into the exercise period).

Blood parameters were only collected at 50 min, not 55 min, and therefore were only analyzed at this 1 time point using a 1-way ANOVA. Similarly, differences in HR and VO2 were compared using a 1-way ANOVA using the data at the 50 min time point only, when the protocol demanded different physical effort of the participants. In the case of the ANOVAs, the data for blood glucose, pH and lactate, as well as HR and VO2 broke the assumption of the homogeneity of variances. In these cases, the Welch and Brown-Forsythe statistics were consulted for overall trial effects. In all cases, post hoc analysis utilized the Tukey’s multiple comparison tests. In order to further investigate if physiological responses could explain differences in cognitive performance, physiological data were plotted against each cognitive test measure using both 50 and 55 min time periods, and blood data for the 50 min time point only. We performed regression analysis (linear as well as polynomial as this fits an inverted-U relationship) using Excel (Microsoft Excel 2010; Microsoft, Redmond, WA, USA). No regression yielded an $R^2$ above −0.08 and therefore no further exploration of relationships was undertaken. Statistical significance was accepted at $p < 0.05$ and values between 0.05 and 0.10 were noted as a difference that may exist. Results and figures are reported as mean ± SD.

### 3. Results

#### 3.1. Cognitive measures

The absolute response time and accuracy scores are presented in Table 1. They provide an example of typical values observed in this investigation. Response time and accuracy scores, expressed as a percent of the session baseline, were used

| Condition | Response time (ms) | Accuracy (%correct) |
|-----------|-------------------|---------------------|
|           | Baseline | 50 min | 55 min | Baseline | 50 min | 55 min |
| Control   | 672 ± 54 | 672 ± 45 | 668 ± 52 | 96.4 ± 3.2 | 95.3 ± 4.2 | 96.2 ± 3.1 |
| Constant  | 677 ± 61 | 648 ± 50 | 634 ± 37 | 96.2 ± 3.4 | 95.1 ± 3.1 | 95.2 ± 4.8 |
| Low       | 660 ± 54 | 643 ± 52 | 634 ± 39 | 95.2 ± 5.7 | 93.6 ± 5.9 | 93.5 ± 5.9 |
| High      | 671 ± 59 | 648 ± 53 | 634 ± 51 | 96.5 ± 2.5 | 93.1 ± 5.4 | 93.8 ± 4.0 |
in the statistical analysis. There was no significant interaction between intervention type and time point for any of the cognitive measures. There was an effect for time point on response time. We have reported on this time effect previously in constant moderate intensity exercise, which showed improvements in cognitive performance with the number of attempts of the cognitive task within a session despite efforts to familiarize participants. There was no trial order effect suggesting familiarization across the study was sufficient. We do not consider this further here.

There was an effect for intervention type on response time \((F(3, 15) = 4.84, p = 0.005; \text{Fig. 3})\). The constant exercise condition was faster than the control condition (mean difference: 4.57% (95%CI: 0.92–8.21), \(p = 0.009\)). The variable high exercise condition (4.47% (95%CI: 0.82–8.12), \(p = 0.011\)), and possibly the variable low exercise condition (3.31% (95%CI: −0.34 to 6.95), \(p = 0.089\)), were also faster than the control condition (Fig. 3A and B). There were no other differences between groups, and no differences between groups for response accuracy (Fig. 3C and D).

### 3.2. Physiological responses

The intervention type had an effect on some physiological responses. Higher blood glucose levels were observed during the variable low exercise intervention compared to the constant (+0.97 mmol/L (95%CI: 0.56–1.38), \(p = 0.001\)) and variable high (+0.85 mmol/L (95%CI: 0.44–1.26), \(p = 0.008\)) exercise conditions. The control condition was not different to any of the exercise conditions. The pH of the capillary samples was lower in the 2 variables conditions compared to both no exercise (variable low: −0.09 (95%CI: −0.12 to −0.07), variable high: −0.09 (95%CI: −0.11 to −0.07), and constant conditions (variable low: −0.08 (95%CI: −0.10 to −0.06), variable high: −0.07 (95%CI: −0.09 to −0.05)), \(p < 0.001\) in all cases. Blood lactate was the highest in the 2 variable conditions, being higher than the constant condition (variable low; +5.7 mmol/L (95%CI: 4.3–7.2), variable high: +5.8 (95%CI: 4.4–7.2), \(p < 0.001\)) which was, in turn, higher than control (+2.5 mmol/L (95%CI: 1.2–3.9), \(p = 0.016; \text{Fig. 4}\)). The \(pCO_2\) values may be lower in the constant condition compared to control (−1.5 mmHg (95%CI: −3.5 to +0.5), \(p = 0.100\), but was lower again in the variable low (−4.0 mmHg (95%CI: −6.0 to −1.2), \(p = 0.009\)) and variable high (−3.4 mmHg (95%CI: −4.7 to −2.1), \(p = 0.027\)) conditions compared to constant condition (Fig. 4). The \(pO_2\) value was higher in the variable low condition compared to all other conditions (no exercise: +7.6 mmHg (95%CI: 3.3–11.9), constant: +9.5 mmHg (95%CI: 5.8–13.2), variable high: +9.1 mmHg (95%CI: 3.6–14.5), \(p \leq 0.003; \text{Fig. 4}\)).

HR and oxygen uptake were expressed relative to individual maximum levels and analyzed using data from the 50 min time point. For HR, the control condition resulted in the lowest value \((p < 0.001, \text{compared to all exercise conditions})\), and the variable high condition was higher than both constant (+10%HR\(_{\text{max}}\) (95%CI: 6–14), \(p = 0.001\)) and the variable low (+10%HR\(_{\text{max}}\) (95%CI: 7–13), \(p < 0.001\)) at 50 min (Fig. 5). For oxygen uptake, all conditions were different from each other \((p < 0.001)\) except for constant and variable low (constant: +7.4%VO₂\(_{\text{max}}\) (95%CI: 1.7–13.2), \(p = 0.064\)) at 50 min which...
trended towards significance (Fig. 5). The control condition recorded the lowest values of oxygen uptake and the highest values recorded in variable high condition.

4. Discussion

The present study provides evidence that improvements in cognitive performance achieved during moderate intensity exercise remain for at least a short time during high intensity exercise, but appear to dissipate shortly after. Consistent with the literature, moderate intensity exercise facilitated cognitive function through an increase in response speed with no difference in decision making accuracy. However, during conditions in which power output was varied to include low and high intensity efforts, the facilitation of performance in this simulated 1-back condition, compared to constant moderate intensity exercise, became less apparent in the period following the high intensity effort. To the authors’ knowledge, this study is the first to investigate cognitive function during both low and high intensity intermittent exercise periods and has important implications for many real world circumstances such as those experienced by emergency service personnel and sports persons. The protocols adopted utilized exercise that resulted in large differences in cardiorespiratory responses, anaerobic metabolism and induced a state of hypocapnia. Although these responses can be theoretically linked to changes in cerebral function, only very weak relationships were observed between physiological measures and cognitive performance.

As we have previously reported, moderate intensity exercise facilitates performance function on this task and the improvement in response time is consistent with other reports in the literature of cognitive tasks. We observed this improvement in response time without losses in accuracy. Dietrich and Audiffren suggest that exercise leads to decreases in function during more cognitively demanding tasks. The facilitation we observed may reflect a relatively low computational requirement of this particular cognitive performance task, or ability to automate the response, therefore not testing the limits of capacity. We believe however that previous literature has typically utilized long cognitive tests, in which performance is assessed, not capable of reflecting the moment by moment changes in physiology likely to influence the brains capacity for cognition. Our choice of a stationary cycle ergometer may also play a role. This type of exercise, unlike a running protocol, will engage less high-order attention allowing greater resources for the cognitive test being undertaken. It is clear that the diverse protocols reported in the literature will influence the results. Further
research is required and the use of short (less than 1 min) cognitive performance tests will play an important role in elucidating cognitive and physical exercise interrelationships.

Overall, we believe the results suggest that cognitive performance does regress back towards control trial performance (i.e., slower response times) shortly after a period of high intensity cycling, and possibly within a high intensity effort. This may be explained by cerebral physiology as pCO₂, a factor strongly associated with cerebral blood flow, was significantly lower at these time points. Unfortunately we were unable to take measures offering further insight into cerebral changes. However, this would be an interesting area for future research as changes during intermittent exercise are likely to be complex given the altering demands placed on the body as a whole.

The lack of an association between any physiological variable and cognitive performance likely attests to the complexity of cognition. We achieved protocols that evoked dramatic changes in physiological responses. Anaerobic metabolism and hypocapnia were evident in both variable conditions despite the conditions resulting in statistically significant differences in cardiorespiratory measures which remained elevated in only the variable-high condition. Hypocapnia results in constriction of cerebral vessels and is generally associated with lower cognitive performance. As we saw similar states of hypocapnia in both variable conditions, this may explain the reduction in the extent of the enhanced cognitive performance observed in these trials compared to moderate exercise. We acknowledge however that our global markers of exercise intensity, such as the capillary samples and cardiorespiratory measures, are not likely to precisely represent changes occurring in the brain.Similarly we did not measure catecholamines which have also been linked to cognitive performance. As discussed earlier, our cognitive performance task may also not be demanding enough to be sensitive to cognitive change in this respect.

It is clear that we need to improve understanding of how exercise intensity can influence cognitive processes. In the present study, we utilized a test, similar to the 1-back condition, which offers the advantage of having a short administration time (45 s) in an effort to allow for more real-time assessments of how changes in power output influence cognitive function. Whilst we did not find decreases in cognitive performance with intermittent exercise, there is some evidence that immediately after, and perhaps even during high intensity exercise there is some compromise. This is likely to have implications for sporting or occupational environments in which periods of high physical effort are required. Research utilizing more demanding, but short, cognitive tasks during intermittent exercise is likely to reveal much more information, as well as reduce the potential for ceiling effects which may have existed in the present study. Future investigations should take into consideration the timing of tasks relative to changes in exercise intensity whilst investigating regional physiological changes in the brain.

5. Conclusion

The present study provides evidence that improvements in cognitive performance achieved during moderate intensity exercise remain for at least a short time during high intensity exercise, but appear to dissipate shortly after. The tendency for a reduced facilitation of cognitive performance with changes in exercise intensity in at least one of the conditions may be related to decreases in cerebral blood flow associated with a hypocapnic state. Despite this rationale, we could not strongly associate any single physiological measure with cognitive performance. Further research utilizing short, but more complex cognitive tasks alongside cerebral physiology measures during intermittent exercise are likely to reveal more information. These areas of research are important as they are likely to assist in many occupational and sporting situations.

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Authors’ contributions

BR and DJS both conceived of the study and its design and coordination. Both authors were involved in the data collection, data analysis and the drafting of the manuscript. Both authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

Neither of the authors declare competing financial interests.

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