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Original research

Exercise improves reaction time without compromising accuracy in a novel easy-to-administer tablet-based cognitive task

Ben Rattray*, Disa Smee

National Institute of Sport Studies, Faculty of Health, University of Canberra, University Drive, Bruce ACT 2614, Australia

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ABSTRACT

Objectives: Moderate intensity aerobic exercise is known to facilitate cognitive performance but new technologies enable increasing opportunities to investigate this phenomenon under different circumstances. This study aimed to describe the effect of exercise on executive function assessed though a novel tablet-based test.

Design: Twenty healthy, active participants volunteered to take part in the randomised fully controlled trial.

Methods: Participants undertook an initial test of maximal aerobic capacity as well as ventilatory threshold during an incremental cycle test. A touch screen tablet computer was placed in the middle of the handlebars at an angle of approximately 45°, and participants were asked to complete the response-inhibition cognitive task (Speed Match, Lumos Labs Inc.) at set time points. A full familiarisation trial was performed prior to subsequent visits, in which participants completed either the control (no exercise) and exercise (90% ventilatory threshold (VT)) trials in a randomised order. During the 1 h trials, the cognitive task was performed prior to, during and post the intervention. Reaction time and accuracy of participant responses were recorded.

Results: Performing the cognitive task resulted in elevated heart rates and ventilation rates during control and exercise. Exercise facilitated performance in the executive function task such that reaction time was enhanced with no change in accuracy. A range of reliability measures are also reported.

Conclusions: This method of assessing executive function during exercise displays face validity and provides promise for further investigation of cognitive function using a simple, short duration, easily administered and widely available test.

1. Introduction

Physical exercise close to ventilatory threshold positively affects basic cognitive task performance[1–3] due to its modulation on the central nervous system.[4–6] Although it is well documented that acute moderate intensity exercise enhances basic cognitive function, it is less clear how exercise effects higher order executive function.[7] Executive function is of interest not only due to the higher order tasks, more akin to real life tasks, but also due to its link with frontal lobe activity[8] which has peak oxygenation during exercise between 60 and 80% of VO_2 max.[9]

One of the first investigations to target the effect of an acute exercise bout on executive function suggested that exercise, even at moderate intensity diminished executive function performance.[10] It is unclear if exercise improves[11] or impairs[7,10] executive function as the type of cognitive task may confuse the findings.[5] Similar studies,[7,11] utilising different cognitive tasks to investigate response execution and response inhibition (a domain of executive function) have observed conflicting results. Whilst response execution was enhanced by exercise in both studies, exercise only improved response inhibition during a stop signal task.[11] These and other common tests used in assessing cognitive function have long administration times (test batteries lasting a total of 18–22 min) and research may miss changes in cognition due to rapid changes in physiology during exercise[12] such as the recovery from brief, high-intensity bouts. Evolving technology, including interactive touch screen tablet computers, promise to provide new opportunities to address these historic limitations. In turn, these advances promise to improve understanding of short-term changes in cognitive ability that may occur with changes in physical load, as can be expected in many sporting and occupational (e.g. military, emergency services) settings.

The present study investigated the effect of an acute bout of moderate-intensity physical exercise on executive function,

* Corresponding author.
E-mail address: ben.rattray@canberra.edu.au (B. Rattray).

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specifically response inhibition. In order to overcome limitations of past research, this study utilised a readily accessible, brief and easily administered protocol that could be undertaken whilst exercising. As exercise intensity is known to influence cognitive performance, this study utilises an intensity closely linked to optimal cognitive performance and cerebral blood flow.[13] The exercise intensity utilised, 90% of an individual's ventilatory threshold, is a common methodological approach in the literature.[14–16] We hypothesised that exercise at a moderate intensity would facilitate the inhibition domain of executive function both during, and immediately post exercise.

2. Methods

Twenty healthy, active participants (10 males aged 26.6 ± 5.2 y; VO_2 peak 55.4 ± 9.7 ml kg min^{-1}; and 10 females aged 24.6 ± 5.6 y; VO_2 peak 43.7 ± 6.1 ml kg min^{-1}) provided informed consent in 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.

An initial maximal cycle test was used to assess peak VO_2 and ventilatory threshold (VT). Participants were instructed on how the cognitive task was to be performed and completed one trial before repeating it in a seated position on the cycle ergometer. Resting oxygen uptake and heart rate measures were taken prior to repeating the cognitive task again. 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 by the researchers so that maximal exertion would be achieved between ~12 and 15 min after completion of the warm-up. Ventilatory threshold was assessed by two independent experienced researchers using three different methods as previously described.[17]

The participant sat on a cycle ergometer (Lode Excalibur, The Netherlands) with upright handlebars. A touch screen tablet computer was placed in the middle of the handlebars at an angle of approximately 45° offering easy access and visual positioning. All testing was performed in an air conditioned laboratory (21.8 ± 1.1 °C, relative humidity 44.9 ± 11.5%).

In the week following the initial test, participants cycled a 1 h familiarisation trial at ~90% VT. The familiarisation trial replicated the timing used in the trials and minor adjustments were made to the workload to ensure the participant could complete the trial. In subsequent visits, participants completed the no exercise ("control") and "exercise" (90% VT) trials in a randomised order. During all trials a cognitive task was performed twice pre-condition, and then at 10, 50, 55 and 1 min post the trial condition. Gas analysis (ParvoMedics TrueOne, UT, USA) and heart rate (Polar Electro, Kempele, Finland) were taken throughout the trials.

In order to facilitate the investigation of an easy to administer and quick cognitive task suitable for broader sporting and occupational use, we investigated cognitive task options available through tablet computer technologies. After some trialling we chose to use the Speed Match task (http://www.lumosity.com/brain-games/speed-games/speed-match, Lumos Labs Inc.), a task that lasts 45 s. Three card patterns are included in this task, however only one of the patterns was utilised for all tasks undertaken. Participants were instructed to perform the task as accurately and as fast as possible prior to each attempt. The task was commenced by the participant touching the screen after instruction from the researcher. We consider that this cognitive task fits within the broad definition of an executive function task as described by Etnier and Chang.[8] As this task requires some inhibition of inappropriate actions we suggest that the task chosen fits most closely with the inhibition response domain of executive function.

Upon completion of the task mean reaction time was recorded along with the number of correct responses and accuracy (number of correct responses divided by total number of responses offered). A "combined" speed and accuracy score was calculated (reaction time divided by accuracy score as a percent) and included in the analysis.

All results are reported as mean ± SD. To investigate reliability of the cognitive measures, the typical error, expressed as a coefficient of variation, across three or more trials was calculated for the cognitive variables using task attempts pre-exercise and at the 10 min time point. Typical error was calculated for the cognitive task immediately prior to beginning the intervention (no exercise or exercise, across four trials) and after 10 min of exercise (across three trials). Intraclass correlations were similarly expressed for these variables and the lower and upper 90% confidence limits of all measures included. Calculations were performed using a freely available excel spreadsheet created for the purpose.[18]

A repeated measures ANOVA with two factors was used to determine the effect of exercise and time on reaction time, accuracy and the combined score from the cognitive task. Each reaction time task attempt was analysed against the corresponding task attempts in each trial condition using planned multiple ANOVAs. Effect size statistics (Cohen's *d*) were calculated using the raw means and standard deviations of the reaction time and combined scores recorded during the task attempt at the 10 min time point. This attempt was selected as it was the time point in which exercise modulated the response the least when compated to the non-exercise condition. To investigate the effect of performing the cognitive task on the physiological response, oxygen uptake, ventilation rate and heart rate were averaged over a minute just prior to the task attempt at the 10 min time point. These values were compared to the same measure taken during the task attempt at the 10 min time point for both the control and exercise condition using a multivariate ANOVA. Statistical significance was accepted at $p < 0.05$.

3. Results

Reliability statistics for the cognitive task during both control and exercise condition are reported in Table 1. Typical error and intraclass correlation statistics have been provided to assist future researchers and practitioners.

There was an effect for task attempt for reaction time only ($p = 0.001$) and no interaction with the exercise trial condition. Reaction time steadily decreased over the duration of the trial such that reaction time during the cognitive task performed at 10 min was slower than at 55 min ($p = 0.002$) and 1 min post the intervention ($p = 0.001$). In addition, reaction time at 50 min was slower than post intervention ($p = 0.022$).

Over the entire trial, exercise had no effect on the accuracy of the cognitive task ($p = 0.724$), however exercise resulted in improved reaction time ($p < 0.001$; see Fig. 1) and combined score ($p = 0.017$) compared to the control condition. At the task attempt at the 10 min time point, when exercise appeared to modulate the response the least, there was still a moderate effect size for both reaction time (Moderate effect size – Cohen's *d*: 0.38; 2.8% faster, range 4% slower to 11% faster) and the combined score (Moderate effect size – Cohen's *d*: 0.35; 3.0% better, range 4% worse to 11% better) when compared to control.

Descriptive data of the physiological responses to the control and exercise condition, taken just prior to initiating, and during the task attempt at the 10 min time point are represented in Table 2. The cognitive task elevated physiological responses during both