Full title: Effects of upright seated and recumbent cycling on cerebral oxygenation and cognition in young, healthy men

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Short title: Effect of exercise mode on oxygenation and cognition

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Abstract

The purpose of this study was to compare the effect of exercise modality on exercise-induced changes in cerebral perfusion and cognitive performance in healthy men. Seventeen physically active men (24.6 ± 4.3y; 1.79 ± 0.05m; 76.5 ± 8.7kg) completed two graded exercise tests (GXT; upright seated and recumbent cycle ergometer) to maximal aerobic capacity and two 30-minute submaximal, moderate-intensity, constant load exercise tests (upright seated and recumbent cycle ergometer). Cognition was assessed using the ‘colour’ and ‘word’ Stroop task, pre- and post- the submaximal exercise tests. Regional oxygenation (rSO_2) to the prefrontal cortex was continuously monitored using near-infrared spectroscopy (NIRS). The upright seated GXT elicited a significantly higher oxygen uptake, heart rate, perception of exertion and power output than the recumbent ergometer (all $P < .05$). A significant increase in rSO_2 was reported between the pre- and post-assessments, regardless of exercise modality ($P < .05$). However, recumbent exercise elicited a significantly higher rSO_2 than upright seated exercise (81.9 ± 6.5 cf. 79.7 ± 9.3%, for recumbent and upright ergometry, respectively). Significant improvements in cognitive performance (Stroop colour and word tasks) were also observed for both tests ($P < .05$); however, there were no differences in cognitive performance between the exercise tests (seated cf. recumbent; $P > .05$). In conclusion, the benefits of enhanced cerebral oxygenation on cognition may be attenuated in a population of young healthy men, and future research should investigate the efficacy of recumbent exercise for patient groups.

Keywords: cerebral blood flow, cognition, regional oxygenation, recumbent, cycling

Introduction

In a healthy population, prefrontal oxygenation, as measured with near infrared spectroscopy (NIRS), demonstrates a quadratic response to incremental exercise (Saitoh et al., 2005). Research has shown that prefrontal oxygenation is either maintained or increased between moderate (30 to 60 % peak oxygen consumption [$\dot{V}O_2$peak]) and heavy (60 % $\dot{V}O_2$peak to ≤ $\dot{V}O_2$peak) exercise intensities, but may decrease at near extreme (≥$\dot{V}O_2$peak) exercise intensities (Bambhani & Mokerjee, 2007; Rooks et al., 2010; Subudhi et al., 2007; Subudhi et al., 2008). As moderate-intensity exercise may augment cerebral perfusion, , this intensity domain may enhance rehabilitation efficacy for certain population groups, i.e., patients diagnosed with stroke or Parkinson’s disease. Recent research has documented that exercises increases cerebral perfusion and oxygenation by promoting neurogenesis and neuroplasticity, and in turn cognitive functioning {Gary, 2014 #983}.Exercise can improve cognition by increasing cerebral blood flow and oxygen delivery, and by elevating brain-derived neruotrophic factor (thought to enhance neurogenesis) {Gary, 2014 #983}. A meta-analysis of 18 randomized controlled trials demonstrated that aerobic exercise improved cognitive function in a number of domains including spatial and executive functioning {Colcombe, 2003 #984}.Recently, the effect of an exercise-induced increase in cerebral blood flow have been investigated during upright cycle ergometry (Lucas et al., 2012, Secher et al., 2008; Subudhi et al., 2007; Subudhi et al., 2008; Subudhi et al., 2009; Yangisawa, 2010). Despite the current popularity of recumbent ergometers in recreational and rehabilitation settings (Egana et al., 2010), such investigations have not been undertaken with this mode of exercise. This is important given that differences are often observed in cardiovascular, respiratory and metabolic responses to upright and recumbent cycle exercise (Quinn et al., 1995; Saitoh et al., 2005). Recumbent exercise has been shown to augment venous return, increase stroke volume and activate a greater proportion of lower limb musculature than upright cycle ergometry (Quinn et al., 1995; Saitoh et al., 2005, Walsh-Riddle & Blumenthal, 1989). This, despite eliciting a significantly slower rate of VO_2 kinetics (Egana et al., 2006; Leyk et al. 1994) and a higher lactate production (Egana et al., 2007; Egana et al., 2006; Leyk et al. 1994). Recently, a greater cardiac output and stroke volume has been shown during recumbent cycle exercise compared with upright cycle exercise soon after the commencement of exercise (Egana et al., 2010). As cardiac output has been shown to have a linear relationship with cerebral blood flow (Ogoh & Ainslie, 2009), independent of cerebral autoregulation and arterial carbon dioxide pressure, it may be postulated that this mode of exercise may also elicit improvements in cognitive function. Accordingly, the purpose of this study was to assess the effects of upright and recumbent cycle ergometry on exercise-induced changes in cerebral perfusion and cognition, in healthy men. It is necessary to establish these relationships in a healthy population prior to any justification being made with regards to the utility of recumbent exercise with patient groups.

Methods

Participants

Seventeen (24.6 ± 4.3 y; 1.79 ± 0.05 m; 76.5 ± 8.7 kg) healthy, physically active men volunteered for this study. All participants were asymptomatic of illness and free from injury, as established by the ACSM participant activity readiness questionnaire and risk stratification procedures (ACSM, 2013). Participants were currently involved in regular, 'recreational' physical activity, undertaking moderate aerobic exercise (> 60-min) three times per week in the months prior to the commencement of the study. All participants provided written informed consent. Ethical approval was granted by the institutional ethics committee.

Procedures

All participants completed four exercise tests; two graded exercise tests (GXT) to maximal aerobic capacity and two submaximal bouts at a moderate constant-load exercise intensity, in a controlled thermo-neutral laboratory environment. Tests were performed on either an upright seated (1 x GXT, 1 x submaximal bout) or recumbent (1 x GXT, 1 x submaximal bout) cycle ergometer in a semi-randomised order, as it was necessary for submaximal exercise tests to proceed the respective GXTs. There was a 48 to 72 hour recovery period between tests. Respiratory gas analysis (oxygen uptake [$\dot{V}O_2$], minute ventilation [$\dot{V}_E$], respiratory exchange ratio [RER]) and heart rate (HR) were continuously monitored during each exercise test. On-line respiratory gas analysis occurred using a breath-by-breath automatic gas exchange system (Sensormedics Corporation, Yorba Linda, CA, USA) following volume and gas calibration. Heart rate was monitored using a wireless chest strap telemetry system

(Polar Electro T31,Kempele, Finland). The Borg 6-20 ratings of perceived exertion (RPE) scale (Borg, 1998) was used to quantify the subjective perception of effort every 3-minutes during the GXTs, and every 10-minutes during the submaximal exercise tests. The display screen of the cycle ergometer (i.e., power output) was concealed from the participant, along with all physiological markers (i.e., $\dot{V}O_2$, $\dot{V}_E$, HR), during each exercise test.

Prior to- and following the seated and recumbent submaximal exercise tests, participants completed a standard cognitive performance test (Stroop task). Continuous wave NIRS (5100C INVOS, Coviden, Bloulder, CO, USA) monitored regional oxygenation (rSO_2) before, during and after exercise.

Exercise Tests:

Seated and recumbent GXT to maximal functional capacity

The GXTs were continuous and incremental, commencing at a low intensity (60 W and 30 W for the upright seated and recumbent GXTs, respectively) and progressively increasing by 1 W every 5 seconds until the participant achieved maximal functional capacity. Participants' peak oxygen consumption ($\dot{V}O_2$peak) and gaseous exchange threshold (GET) were ascertained for both exercise tests. The GXTs were used to determine the exercise intensities that would be prescribed in both the seated and recumbent submaximal exercise tests.

Submaximal exercise tests

The V-slope method (Beaver et al., 1986) was used to analyse the slopes of $\dot{V}O_2$ and carbon dioxide ($\dot{V}CO_2$) volume curves from both the seated and recumbent GXTs to determine each participants power output at GET. The GET typically equates to a moderate exercise intensity (45-60% $\dot{V}O_2$max) (Seiler & Tønnessen, 2009). During the seated and recumbent submaximal exercise tests, participants cycled at a power output equivalent to GET for 30-minutes.

Cognitive assessments

Prior to each submaximal test, and following 5-minutes of quiet seated rest, all participants completed the Stroop task, a classic measure of prefrontal cortex function (MacLeod, 1991). The Stroop has been widely used to assess the effects of acute exercise on cognitive function (Hogervorst et al., 2008; Lucas et al., 2012; Vasques et al. 2011). The Stroop task demonstrates the reaction time of a task and requires participants to name a colour (i.e., "blue," "green," or "red”) when printed in a colour not denoted by the name (e.g., the word "red" printed in blue ink instead of red ink). Both the ‘word’ and ‘colour’ version of the Stroop task were implemented. On completion of the exercise test participants remained in their upright or recumbent position, and following a 5-minute recovery period repeated the Stroop task.

NIRS

Regional oxygenation (rSO_2) was continuously monitored using NIRS, during both the Stroop tasks and throughout the exercise protocols. Sensors were placed bilaterally over the contra-lateral frontal lobe, approximately 3 cm from the forehead midline and immediately above the supra-orbital ridge. NIRS assessments have been demonstrated to provide a metric of cognitive activation similar to fMRI during cognitive performance tasks (Cui et al., 2011).

Data Analysis

Paired sample t-tests compared peak physiological, physical and perceptual responses from the seated and recumbent GXT. When considering the submaximal exercise tests, two-way repeated measures analysis of variance (ANOVA): Test (seated, recumbent) by Time (pre, post) were used to compare the time to complete the Stroop tasks (colour, word) and the rSO_2 between the two modes of exercise. A similar analysis was used to assess the rate of change in rSO_2 before, during and following (baseline, 10-min, 20-min, 30-min post) the submaximal exercise tests. A two-tailed paired samples t-test was used to compare the time to steady state during the seated and recumbent exercise tests. Effect sizes were established using Cohen's d (Cohen, 1992), and Alpha was set at 0.05 and adjusted accordingly.

Results

Peak values at the termination of the seated and recumbent GXT are reported in Table 1. tThe seated GXT elicited a significantly higher VO_2, HR, RPE and power output than the recumbent GXT (all $P < .05$). When expressed as a proportion of the peak values, there were no differences in the power output or VO_2 calculated at GET from the seated (48.3 ± 4.3 and 47.7 ± 7.4 %, respectively) and recumbent (48.4 ± 5.2 and 47.5 ± 5.3%, respectively) GXT ($P > .05$).

Stroop task; pre- and post exercise

Although a non-significant Test (seated, recumbent) by Time (pre, post) interaction was reported for the time to complete the Stroop tests (word, colour) (P > .05), a Time main effect was observed (P < .001). Post-hoc analysis demonstrated significant improvements in the time to complete the Stroop tests (word and colour) following both seated and recumbent submaximal exercise (both P < .05; Table 2). The rSO_2 responses during the pre-exercise Stroop task were statistically similar between exercise modes (75.1 ± 9.0 and 76.7 ± 6.7 % for seated and recumbent exercise, respectively; P > .05). Significantly higher values were reported during the post-exercise Stroop task (81.5 ± 10.6 % and 83.8 ± 6.9 % for seated and recumbent exercise, respectively), compared to the pre-exercise Stroop task (P < .001).

Oxygen saturation (rSO_2) during exercise

Although there was no Test by Time interaction for rSO_2 (P > .05), a Test main effect was approaching significance (P = .06), with a higher mean rSO_2 value reported for recumbent exercise compared to seated exercise (81.9 ± 6.5 cf. 79.7 ± 9.3 %, respectively). A significant Time main effect was also demonstrated (P < .001). Post-hoc analysis revealed a significant increase in rSO_2 between baseline and 10-min (P < .001; Figure 1). The time to achieve steady state was similar for seated and recumbent exercise (593 ± 283 cf. 569 ± 219 s, respectively; P > .05).

Discussion

The present study has demonstrated that 30 minutes of submaximal upright and recumbent cycle exercise elicited statistical improvements in cognitive performance (Stroop task) in a population of young healthy men. Despite a greater regional oxygenation (rSO_2) of the pre-frontal cortex during recumbent exercise compared to upright cycle ergometry, improvements in cognition were similar for both exercise modes. Thus, there exists a more complex pathway between exercise and improved cognition than simply an increase in cerebral blood flow and tissue oxygenation.

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The improvement in cognitive function following moderate intensity exercise is in accordance with previous research (Chang et al., 2012; Lambourne & Tomporowski, 2010; McMorris et al., 2011; Tomporowski, 2003). In this study, 30 minutes of submaximal exercise generated a 4-6 % and 5-7 % improvement in Stroop task performance (for word and colour Stroop, respectively), regardless of the exercise mode. The improvements in cognitive performance may therefore, at least in part, be associated with the observed exercise-induced increase in cerebral blood flow. Previous research has shown that exercise intensities up to and including ~60 % VO_2peak may produce elevations in cerebral blood flow (Ogoh & Ainslie, 2009). Indeed, in this study, whilst exercising at ~48 % of VO_2peak (equivalent to GET), a 5-6 % increase in regional oxygenation was observed. An exercise-induced increase in cerebral blood flow is related to an increase in brain neuronal activation and metabolism (Ide et al., 1999; Lucas et al., 2012; Secher et al., 2008), of which neurovascular coupling has been identified as an important mechanism for adequate oxygen delivery (Girouard & Iadecola, 2006; Lucas et al., 2012). However, the statistically higher (~2.2 %) regional oxygen saturation during recumbent exercise did

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not elicit any further improvements in cognition over and above that observed with upright cycling.

This study utilised a group of young, physically fit men who were accustomed to moderate intensity aerobic exercise, and who did not exhibit any obvious signs of impaired cognition prior to commencing exercise. Thus, for the current cohort, there may have been a limited capacity for temporal improvements in cognition following enhanced cerebral oxygenation. Enhanced cerebral oxygenation, as identified during recumbent exercise, may be of greater benefit to certain low-fit and/or patient groups, including those diagnosed with stroke or Parkinson's disease. Of note, recumbent cycling exercise has been shown to be a safer alternative to upright cycling, and may provide practical advantages for muscle and aerobic training in patients with impaired physical function (Gregor et al., 2002; Kerr et al., 2007). Thus, the relationship and underlying mechanisms associated with exercise-induced changes in cognition should be examined in such patient groups.

Future research investigating the temporal relationship between aerobic exercise and cognition should ensure the exercise perturbation is of a sufficient duration. For example, Lucas et al. (2012) recently investigated the effect of age on exercise-induced (upright cycling) alterations in cognitive executive function (Stroop task). Two exercise intensities were prescribed, 30% and 70% of heart rate range, with each intensity lasting 8 minutes and the higher intensity following the lower intensity. The authors reported that the higher exercise intensity elicited greater improvements in cognitive function. For the current study, it took participants, on average, 9.5 minutes (range: 1.8 - 21.7 minutes) to achieve steady-state regional oxygen saturation during both upright seated and recumbent cycle exercise. Based on our study findings, it may be postulated that the study by Lucas et al. (2012) may have underestimated the magnitude of change in cognitive performance elicited by exercise, and/or potentially came to an erroneous conclusion with regards to the importance of exercise intensity.

The small sample size (n = 17) and homogenous cohort may have influenced the findings of the current study. Future research should attempt to replicate the current student design with a larger, more heterogeneous group, including patient groups with known cognitive impairments. Furthermore, mechanistically, we isolated regional oxygen saturation and did not attempt to address the changes in concentration of deoxygenated haemoglobin, total haemoglobin and oxygenated haemoglobin, during- and following recumbent exercise. In particular, future studies should monitor total haemoglobin, to enable interpretation of regional perfusion as well oxygen saturation. It is also noted that the researchers did not include a control condition wherein Stroop task performance was assessed following 30 minutes of seated rest.

In conclusion, the present study has demonstrated that 30 minutes of moderate intensity upright seated or recumbent cycle exercise has the potential to elicit significant improvements in cognitive function in young, physically fit males. While greater changes in regional oxygen saturation to the prefrontal cortex were found for the recumbent compared to upright exercise, both modalities elicited similar improvements in cognitive function. Considering greater improvements in regional oxygen saturation were found for the recumbent compared to upright exercise, further research into the clinical utility of recumbent exercise for patients with known cognitive impairments, e.g., stroke, is warranted.

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Conflicts of interest: None to declare

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Figure Legend:

Figure 1: Mean (± SD) oxygen saturation (rSO_2) before (baseline), during (10, 20, 30-min) and after (post) exercise for seated and recumbent exercise