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The effects of low-intensity cycling on cognitive performance following sleep deprivation

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ABSTRACT

This study examined the effect of 24 h of sleep deprivation on cognitive performance and assessed the effect of acute exercise on cognitive performance following sleep deprivation. Young, active, healthy adults ($n = 24$, 14 males) were randomized to control (age = 24.7 ± 3.7 years, BMI = 27.2 ± 7.0) or exercise (age = 25.3 ± 3.3 years, BMI = 25.6 ± 5.1) groups. Cognitive testing included a 5-min psychomotor vigilance task (PVT), three memory tasks with increasing cognitive load, and performance of the PVT a second time. On morning one, cognitive testing followed a typical night's sleep. Following 24-h of sustained wakefulness, cognitive testing was conducted again prior to and after the acute intervention. Participants in the exercise condition performed low-intensity cycling (~ 40%HRR) for 15-min and those in the control condition sat quietly on the bike for 15-min. *t*-Tests revealed sleep deprivation negatively affected performance on the PVT, but did not affect memory performance. Following the acute intervention, there were no cognitive performance differences between the exercise and rested conditions. We provide support for previous literature suggesting that during simple tasks, sleep deprivation has negative effects on cognitive performance. Importantly, in contrast to previous literature which has shown multiple bouts of exercise adding to cognitive detriment when combined with sleep deprivation, our results did not reveal any further detriments to cognitive performance from a single-bout of exercise following sleep deprivation.

1. Introduction

Prolonged wakefulness, through acute sleep deprivation or sleep restriction, can be detrimental to human performance and cognitive outcomes [1]. Although chronic sleep restriction (i.e. reduced sleep time) is more common, acute sleep deprivation (i.e. no sleep) can be experienced on occasion and can be common in some occupational fields such as healthcare [2] and transportation [3]. There is substantial evidence showing that sleep deprivation increases the risk for human-error related accidents, with studies consistently showing that acute sleep deprivation causes individuals to perform similarly to intoxicated individuals [4,5] and with one well-designed study indicating that performance after acute sleep deprivation was similar to performance in individuals with a blood alcohol content of 0.05–0.1% [6]. Considerable research has explored the effects of sleep deprivation on motor function and driving performance ([7,8]) and has examined its influence on cognition [9]. Studies exploring the effects on cognition have demonstrated that sleep deprivation adversely affects working memory [10–12], attention [13,14], and reaction time [12,14–16]. It has been suggested that sleep deprivation lowers arousal, which can decrease neural efficiency or capacity (i.e. available cognitive reserves), thus blunting cognitive performance, unless additional arousal is elicited [17,18]. Acute interventions that can increase arousal and improve cognitive performance, such as exercise, should be considered.

1.1. Cognitive performance and exercise

Though many studies have focused on neurobiological responses to sleep deprivation and have highlighted the negative implications for cognitive performance, few have examined acute interventions to counter the expected deficits. One possible behavioral intervention to consider is acute exercise because of its demonstrated positive effect on cognitive performance and its elevation of arousal. With respect to the effects of exercise on cognitive performance, meta-analyses have found that an acute bout of exercise has a small, but positive effect on cognitive performance by children, young adults, and older adults [19,20]. Lambourne & Tomporowski suggested that acute exercise may improve rapid decision-making and automatic processing during exercise due to

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increases in arousal, however the physiological changes that remain after exercise may contribute to enhanced performance on more complex cognitive tasks such as memory processing. Exercise-induced arousal may increase the available reserves for basic attentional processing allowing necessary resources to be allocated for higher-order functioning. In addition to exercise-induced arousal, task complexity may affect task-specific performance outcomes after acute exercise. For example, Chang et al. [21] found an increase in activation in brain regions associated with arousal and higher-order processing after acute exercise in healthy, young adults. However, behavioral improvements were only found during complex tasks. These specific improvements may suggest a ceiling effect for simple tasks, in regard to exercise-induced arousal improvements, in a state where cognitive reserves are not decreased; however, tasks that are complex and elicit higher-order functioning may have a decreased threshold for arousal-induced improvements. According to the cognitive reserve theory, there needs to be some level of detriment to the reserves in order for significant improvements to occur in response to an intervention [22]. The detriment may be derived from the current status and demands placed on the individual, such as sleep deprivation, or by chronic conditions, such as aging or chronic disease. Given this evidence and the predictions of the cognitive reserve theory, it is anticipated that acute exercise may be beneficial for cognitive performance in sleep-deprived individuals in whom reserves are decreased.

1.2. Exercise and sleep deprivation on cognitive performance

Surprisingly, to our knowledge there is no research available on the effects of acute aerobic exercise as an intervention to counteract cognitive performance deficits associated with sleep deprivation. In the sleep deprivation literature, studies that have focused on exercise have used exercise as an additional stressor, and thus have specifically designed the exercise to be particularly challenging when coupled with sleep deprivation. Not surprisingly, these studies have tended to find that exercise combined with sleep deprivation results in negative effects. For example, performing multiple bouts of exercise every 2 h throughout a night of sleep deprivation has been shown to either have no impact on cognitive performance [23] or to negatively impact reaction time, attentional lapses, and mood [24]. Additionally, pairing continuous aerobic exercise with sleep deprivation, during an ultra-endurance event, resulted in deleterious effects on reaction time, attentional lapses, and false alarms during a psychomotor vigilance task [25]. These findings suggest that exercise paired with sleep deprivation may be designed in a way so as to add to the total physiologic load on the mind and body, decreasing performance in simple tasks, rather than increasing available reserves.

Despite this evidence that suggests multiple bouts of acute exercise or continuous exercise coupled with sleep deprivation has a negative effect on cognitive performance, the well-established beneficial effects of exercise in the absence of sleep deprivation suggest that it might be possible to use a single bout of exercise as a means of increasing arousal and, hence, improving cognitive performance following sleep deprivation. Although low, moderate, and vigorous intensity acute aerobic exercise can improve cognitive performance in a variety of populations, a single bout of low intensity exercise may benefit sleep-deprived individuals by increasing arousal and enhancing cognitive reserves, but without taxing the system to the point that deleterious effects on cognitive reserves would be seen. Hence, our purpose was to examine the changes in cognitive performance following 24 h of sleep deprivation and to assess the effects of a single bout of low-intensity exercise during the deprived state. We hypothesized that sleep deprivation would have a detrimental effect on cognitive performance, with greater effects on simple tasks, and that a single bout of low-intensity cycling would counter those deficits.

2. Method

2.1. Participants

Participants consisted of 30 young adults volunteers recruited from undergraduate and graduate classes and the community. Inclusion criteria were that participants were required to have a regular sleep pattern (self-reported 8 or more hours of sleep per night with onset typically occurring between 10 pm to midnight during the previous week), to self-report 6–8 h of sleep the night prior to participation in the study (i.e., not to be acutely sleep deprived before the beginning of the study), and to be recreationally active (self-report 30 min per day, 5 days per week, for the past 3 months). One participant was excluded for being acutely sleep deprived, two participants were excluded due to technical issues with sleep monitoring, and three participants were excluded for unforeseen events, which led to termination of testing during night two. The final sample consisted of 24 young adults (20–30 years). Participants were asked to refrain from participation in exercise 24 h prior to the first testing session and to abstain from caffeine prior to testing on morning one. All other typical daily patterns were maintained. Based upon self-reported medication use, none of the participants were taking any medications that would be expected to influence sleep and self-reported caffeine intake between morning one and evening two ranged from 0 to 4 caffeinated beverages (M = 0.625 SD = 1.21). The University of North Carolina at Greensboro Institutional Review Board approved the testing protocol and all participants gave written informed consent and completed demographic questionnaires prior to participation.

2.2. Protocol

2.2.1. Overview

This study required 48 h of data collection for each participant. Prior to the start of the study, participants met with researchers for consenting, explanation of procedures, and questionnaires. Their activity and sleep were tracked with an accelerometer from that point until the completion of the study. After a typical night's rest at home (evening one), participants came to the lab for morning one procedures. After testing, the participants went about their typical day, avoiding napping or exercise, and returned to the lab that evening for overnight monitoring (evening two). Following 24 h of sustained wakefulness, morning two testing began. Morning two consisted of two cognitive testing sessions, one prior to and one after the intervention. Participants either exercised in between cognitive testing sessions or rested. The protocol is described in more detail below and depicted in Fig. 1.

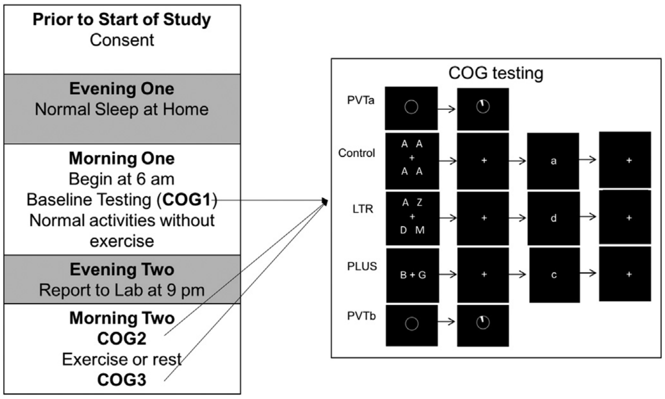

Fig. 1. Testing protocol with a visual display of the cognitive (COG) testing battery including Sternberg memory tasks (Control, LTR, PLUS) and psychomotor vigilance tasks (PVTa, PVTB) in testing order with examples for the Sternberg memory task indicating situations when the participant should respond that the letters match.