Assessing the Impact of Acute Aerobic Exercise on Cognitive Performance

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Abstract

Many studies have demonstrated the benefits of aerobic exercise, such as improved metabolism, strengthened muscle groups, enhanced physical fitness, and potential anti-aging effects. Additionally, research has suggested that aerobic exercise may have a positive impact on mood regulation and the alleviation of negative emotions. This study employs eye tracking as a measurement tool to investigate the influence of acute aerobic exercise on cognitive performance. Participants were randomly assigned to exercise and non-exercise groups. Those in the exercise group engaged in a five-minute session of acute aerobic exercise, followed by a return to normal heart rates. Subsequently, exercise and non-exercise group participants completed reading comprehension tasks, during which an eye tracker tracked their eye movements. According to the eye-tracking results, acute aerobic exercise did not significantly improve participants' cognitive task performance.

Meanwhile, it was found that short time and high-intensity exercise negatively affected attentional shifting during the tasks. Participants in the exercise group exhibited delayed attentional transfer. This study contributes to the existing body of knowledge by shedding light on the intricate relationship between acute aerobic exercise and cognitive performance. The findings offer recommendations for brief exercise breaks during work or study. Moreover, it is a valuable resource for researchers by offering new insights and methodologies for future investigations.

Keywords: cognitive task, acute aerobic exercise, eye tracking, reading comprehension

1. Introduction

Physical exercise has played a pivotal role throughout human history. In ancient societies, physical movement was essential for survival as individuals navigated their environment to evade threats and secure sustenance (Contributor, 2014). In the modern era, exercise is not merely a survival imperative but has evolved into a cornerstone of a healthy lifestyle. People now exercise to enhance their physical well-being and maintain an appealing physique (Blanchette, Ramocki et al., 2005). Moreover, a growing body of research has illuminated the positive impact of exercise on mental health, including its capacity to alleviate negative emotions such as depression, anxiety, and stress (Lecheminant, 2014; Miyazaki, 2014). Exercise is a source of emotional well-being, nurturing a positive outlook on life. This burgeoning interest in the relationship between aerobic exercise and mental functioning has generated noteworthy insights. For instance, a study discovered that individuals with exercise experience exhibit heightened activation of their language systems when processing action language (Beilock, Lyons et al., 2008). Similarly, Thomas et al. identified the capacity of long-term exercise to influence brain structure, bolstering individual brain health (Thomas, Dennis et al., 2012). In parallel, studies have demonstrated the favorable impact of short-term, aerobic exercise on various aspects of cognitive function, encompassing executive control (Hall, Smith, et al., 2001), decision-making ability (McGill, Kavcic et al., 2006), working memory (Tomporowski, 2003), cognitive flexibility (Netz, Tomer, et al., 2007), and more.

Researchers have employed diverse methodologies to investigate the effects of acute aerobic exercise. For instance, Hu's (2014) research leveraged sprinting exercise to evaluate the influence of exercise on cognition, ultimately concluding that exercise promotes cognition. Conversely, Shi (2022) utilized the Stroop paradigm to examine cognitive task performance following acute aerobic exercise and found no significant effect. Many studies have adopted the reaction time paradigm to explore this domain (Zhang, 2019). This study seeks to explore the impact of acute aerobic exercise on cognition using an innovative eye-tracking method. Eye-tracking technology offers immediate, cost-effective, and non-invasive advantages. The primary objective of this research is to apply eye-tracking technology to investigate cognitive benefits associated with motor skills. The aim is to expand this field's technological horizons and procure more effective and sensitive technical indicators for future research endeavors. Additionally, whereas most prior studies employed relatively extended exercise durations, this study embraces a paradigm of short-duration, high-intensity exercise designed to simulate brief work or study breaks. The results are anticipated to benefit students and office workers by guiding relaxation, ultimately enhancing work efficiency.

2. Methods

2.1 Participants

A total of 20 individuals (Mean Age = 26.89, Standard Deviation = 5.73) were selected randomly, comprising an equal split of 10 females and ten males. These participants were then further divided randomly into two groups: the exercise group (Group E) consisted of 10 participants, while the non-exercise group (Group N) also included 10 participants.

2.2 Stimuli

This study utilized three reading comprehension tasks as its experimental materials. Each task comprised a passage of approximately 200 words and a single question. The selected passages deliberately avoided using uncommon or esoteric characters or terms to mitigate the influence of varying cognitive abilities and education levels among participants. Furthermore, all questions were designed to have their answers explicitly provided within the passages. The three passages covered diverse topics, encompassing literature, art, and mathematics, and were labeled R1, R2, and R3, respectively. For R1 and R2, the questions were structured as multiple-choice questions, each featuring a single correct answer. In contrast, the questions for R3 were designed to have multiple correct answers, adding an element of complexity to the task.

2.3 Design and Procedure

This study adopted a between-subject design. Participants were randomly assigned to one of two groups. Before the commencement of the experiment, each participant received comprehensive information regarding the study's procedures and potential risks. Participation was strictly voluntary, and all participants provided informed consent by signing the requisite forms.

For Group E, participants wore exercise bracelets to monitor their heart rates. They were instructed to engage in a 5-minute session of acute aerobic exercises, specifically the open and close jump until their heart rates increased by 30 beats per minute from their baseline heart rate. Subsequently, participants in this group rested until their heart rates returned to their original levels. The reading comprehension tasks were then introduced. In contrast, participants in Group N did not engage in any exercise regimen. However, they were also required to wear exercise bracelets beforebefore the experiment to ensure their heart rates remained within the normal range. Before initiating the reading comprehension tasks, all participants were seated in front of a screen connected to a laptop and equipped with an eye tracker (Tobii 4C). A nine-point calibration process was conducted to facilitate accurate eye tracking.

Subsequently, the three passages and their associated questions were presented sequentially on the screen. Following the completion of the experiment, each participant received snacks as a token of appreciation. The experiment's areas of interest (AOIs) encompassed the Passage, Answer (indicating the correct choices), and Question. Eye tracking data, including Total Fixation Duration (TFD), Fixation Count (FC), Average Fixation Duration (AFD), and First Fixation Duration (FFD), were recorded to analyze participants' visual processing behaviors when viewing the stimuli. Statistical analysis was performed to detect potential differences between the two groups.

2.4 Data Analysis

To assess potential differences in gaze behaviors between Group N and Group E, between-group t-tests were conducted for TFD, FC, AFD, and FFD. These analyses aimed to elucidate the impact of exercise on participants' performance in reading comprehension tasks.

3. Results

3.1 Between-Group T-test Analysis - Answer

As presented in Table 1, there was no significant difference in Total Fixation Duration (TFD) between Group N (M = 2.43, SD = 1.31) and Group E (M = 2.69, SD = 1.17) ($t = 1.73$, $p > 0.05$). Similarly, the Fixation Count (FC) did not significantly differ between Group N (M = 12.14, SD = 5.39) and Group E (M = 13.33, SD = 5.58) ($t = 1.74$, $p > 0.05$). Average Fixation Duration (AFD) showed no significant variance between Group N (M = 0.18, SD = 0.04) and Group E (M = 0.19, SD = 0.14) ($t = 1.76$, $p > 0.05$). However, a significant difference was observed in the First Fixation Duration (FFD) between Group N (M = 0.19, SD = 0.06) and Group E (M = 0.25, SD = 0.08) ($t = 1.75$, $p < 0.05$).

3.2 Between-Group T-test Analysis - Question

Table 1 illustrates the results for Total Fixation Duration (TFD) between Group N (M = 5.57, SD = 2.93) and Group E (M = 4.49, SD = 0.97), showing no significant difference ($t = 1.76$, $p > 0.05$). Fixation Count (FC) similarly exhibited no significant distinction between Group N (M = 26.07, SD = 11.86) and Group E (M = 21.54, SD = 4.68) ($t = 1.75$, $p > 0.05$). Average Fixation Duration (AFD) also did not significantly differ between

Group N (M = 0.21, SD = 0.06) and Group E (M = 0.22, SD = 0.04) (t = 1.73, p > 0.05). However, the First Fixation Duration (FFD) demonstrated a significant discrepancy, with Group N (M = 0.15, SD = 0.04) being significantly lower (t = 1.75, p < 0.05) than Group E (M = 0.20, SD = 0.05).

3.3 Between-Group T-test Analysis - Passage

Table 2 reveals that the Average Fixation Duration (AFD) for the entire passage displayed no significant difference between Group A (M = 0.17, SD = 0.06) and Group B (M = 0.19, SD = 0.04) (t = 1.73, p > 0.05).

Table1:The Result of TFD, FC, AFD, and FFD for Question and Answer

Group	AOI	TFD(s)	FC	AFD(s)	FFD(s)
Group A	Answers	2.43	12.14	0.18	0.19
	Questions	5.57	26.07	0.21	0.15
Group B	Answers	2.69	13.33	0.19	0.25
	Questions	4.49	21.54	0.22	0.20

Table2:The Result of AFD for Passage

Group	AFD(s)
Group A	0.17
Group B	0.19

4. Discussion

This study aimed to examine the impact of short, high-intensity aerobic exercise on cognitive performance, using reading comprehension tasks to measure cognitive ability. Eye-tracking technology was employed to record participants' reading behaviors, allowing for collecting precise and quantitative data. The participants were divided into exercise and non-exercise groups. In the context of this study, higher Total Fixation Duration (TFD), Fixation Count (FC), and First Fixation Duration (FFD) values suggest lower processing efficiency, indicating that participants took longer and required more fixations to comprehend the texts. On the other hand, a lower Average Fixation Duration (AFD) reflects a higher cognitive load during the reading process.

The data analysis revealed that participants' performance in reading comprehension tasks was not significantly influenced by whether they engaged in exercise. There were no substantial differences in TFD, FC, and AFD between the exercise and non-exercise groups for answers and questions. However, a notable distinction was observed in the First Fixation Duration (FFD) for answers and questions between the two groups. The FFD of the exercise group was significantly higher than that of the non-exercise group, signifying that participants in the exercise group experienced a delay in attention shifting during the reading task.

The effects of acute aerobic exercise on cognitive performance are subject to various moderating variables, including exercise intensity, exercise type, temporal paradigms, and individual characteristics. Previous research, such as the Yerkes-Dodson law, has proposed an inverted U-shaped relationship between arousal level and exercise performance. Similarly, cognitive performance shows an inverted U-shaped curve concerning exercise intensity. In this study, the participants engaged in approximately five minutes of high-intensity aerobic exercise, which did not significantly impact cognitive performance. This is consistent with the findings of McMorris and Hale (2012), which indicated that moderate-intensity acute aerobic exercise had a notably larger effect on cognitive tasks than low- and high-intensity exercise. Additionally, studies, like Kamijo (2009), have reported that high- and low-intensity acute aerobic exercises did not significantly affect cognitive processes such as attention and cognitive flexibility. The sequential paradigm employed in this study, which required participants to complete cognitive tasks after their heart rates had returned to normal, could explain why no differences were observed between the exercise and non-exercise groups.

Participants in the exercise group exhibited significantly higher FFD for answers and questions, indicating a delay in attention shifting. Attention diversion difficulty refers to the challenge of actively and promptly shifting mental focus from one task to another. This phenomenon, often observed in dyslexic children (Lv, 2013), can impact reading outcomes. In this study, the exercise group experienced attention shift delays, suggesting a negative impact of short time and high-intensity aerobic exercise on cognitive tasks. While these findings align with previous research (Davranche & McMorris, 2009; Soga, K., 2015), it is important to note that Liu (2022) reported significant improvements in attention transfer function following acute aerobic exercise. This discrepancy could be attributed to variations in exercise type and intensity. Liu's study involved 20 minutes of basketball exercise, which falls under moderate-intensity aerobic exercise, unlike the high-intensity exercise in the present study. Moreover, Liu's participants were professional basketball players, likely possessing heightened athletic abilities and exercise proficiency, further contributing to the contrasting results.

Future research could expand on the present study in several ways. Investigating how gazing behaviors change with varying exercise intensity levels and durations would provide a more comprehensive understanding of the subject. Additionally, future research might explore the impact of exercise on attention from diverse participant perspectives, considering factors such as gender, age, and exercise habits. This holistic approach could contribute to a more comprehensive exploration of the topic.

5. Conclusion

This study aimed to examine the impact of short-time and high-intensity exercise on cognitive performance, to simulate the cognitive effects of a brief respite, akin to a short break during work or study. The study harnessed eye-tracking technology to monitor participants' gaze behavior as they engaged in reading comprehension tasks, drawing comparisons between the exercise and non-exercise groups. The experimental results revealed that short bouts of high-intensity acute aerobic exercise did not substantially enhance cognitive performance. The exercise regimen displayed a somewhat adverse effect on cognitive function by inducing delays in participants' attention shifts. These findings suggest that high-intensity aerobic exercise during brief interludes does not significantly boost cognitive performance. Rather, it may elicit minor detrimental effects. Additionally, this study employed eye-tracking technology, representing a pioneering approach to investigating the complex interplay between exercise and cognition. This innovative methodology provides fresh insights into the field and can serve as a valuable reference for future research endeavors.

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