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Physical Exhaustion Induced Variations in Event-Related Potentials and Cognitive Task Performance in Young Adults

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Event related potential · Cognitive performance · Exhaustion · Stroop test

Abstract
Background/Aims: Physical exhaustion is not always peripheral, and it is the brain that causes the sensation of fatigue either due to decrease of metabolic resources or due to central activation process that regulates attention and performance. This study was undertaken to observe the variations in event-related potentials (ERPs) and cognitive performance after an exhausting physical exercise. ***Methods:*** A total of 60 healthy young adult subjects were included in the study. The study was conducted in 2 phases with at least a week gap between the phases. The participants answered a Multidimensional Fatigue Inventory (MFI-20) questionnaire before and after trials in each phase to measure the induced physical exhaustion. In phase I (control trial), the ERP data were processed using P300, Standard auditory "oddball paradigm," on computerized evoked potential recorder (RMS EMG MK-2) using 10/20 system to know the engagement of attention after which participants were given to perform cognitive tasks such as "Stroop Test, Trial Making Test and Mini Mental State Examination." In Phase II (exercise trial), the participants were instructed to cycle as hard as they could, till they could not continue anymore, which was followed by recording of P300-evoked potentials and performance of cognitive tasks as in Phase I. Paired *t test* was used to compare between any dependent variables. ***Results:*** Fatigue-related subjective measures (MFI-20) showed that both mental and physical exhaustion were significantly greater in the exercise-involved cognitive trial than in the control trial. Lower P300 latencies reflect faster reaction time; however, their response accuracies were poorer resulting in poorer cognitive performances. Participants subjected to control trial performed better in terms of higher percentage accuracy but with slow reaction time. ***Conclusion:*** The participants experienced more fatigue physically and mentally during the exercise that involved cognitive tasks. An apparent decrease in attention based on decreased percentage accuracy of response was evident, implying that fatigue, performance, and attention are interdependent.

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Introduction

Everything about our existence in today's world is moving at such a fast pace that it just leaves many people in our modern society feeling overwhelmingly exhausted [1, 2]. Exhaustion is defined as a decline in the ability and efficiency of mental and/or physical activities that are caused by excessive mental and/or physical activities. Fatigue can be either physical or mental and is often accompanied by peculiar sense of discomfort, desire to rest, and reduced motivation. Fatigue can manifest in potentially impaired cognitive function and has been shown to involve more complex neural mechanisms related to cognitive task performance [1, 3].

The epidemiology of chronic fatigue has mainly been described in developed and developing countries, where a considerable proportion of people are often found to have fatigue-related somatoform disorders or mental disorders such as depression and anxiety [4, 5]. Previous research on specific group of people (pilots, drivers, and so on), engaged in work requiring a good attention and accuracy, has reported difficulties with concentration and attention during tasking when they are fatigued, resulting in adverse consequences on task performance [2, 6–8].

Attention, a prominent feature of dynamic human behavior, is particularly affected by mental exhaustion. Lack of attention results in improper (biased) processing of incoming information for its relevance [9]. Event-related potential (ERP) measures (P300) are directly related to the allocation of attention resources during stimulus engagement with increased latency indicating longer processing time [10]. Available meta-analysis and review associates increased amplitude and short latency relative to basal rate following bouts of exercise in adults, indicating significant improvement in cognition [11, 12].

To date there have been few research on the effect of exhaustion on cognition throughout the world. Comparatively little is known about the phenomenon and physiology of cognitive fatigue. However, the existing literature has demonstrated that specific task and intensity of task induce fatigue, which in turn influences the performance [13–15]. Further neurophysiological studies support a possible role of fatigue in mediating many of the behavioral effects associated with cognitive performance [16, 17].

The effect of physical activity on cognition has grown in interest in recent years with substantial reports indicating a beneficial effect on cognitive processes through isolated acute bouts of exercise [18, 19]. The physical activity has also been observed to bring an increase in cognitive performance. However, the conflicting studies do exist reporting limited or no influence of physical activity on cognition [20, 21].

In many respects, it appears that the effect of physical exhaustion on attention and performance is still inconsistent and not documented in Indian population. Hence, the present study is undertaken as an attempt to explore the effect of an exhausting physical exercise on cognitive performance among young adults.

Methodology

This cross-sectional interventional study was conducted in Davangere, India. The selected subjects were apparently healthy young adults aged 21.5–31.9 years. A thorough history about existing medical conditions and medications taken in past 6 months was obtained followed by clinical and systemic examinations. Subjects with established cardiopulmonary diseases, unstable coronary syndromes, and on vigorous athletic training exercises were excluded.

The sample required was estimated using the formula $n = (Z_{a/2})^2 s^2/d^2$, the pilot study conducted on 5 healthy young adults, yielded a SD of 4.7 at confidence interval of 95% and error rate of 5% resulted in the minimum sample size required to be 27 subjects; however, after allowance of additional 10%, the corrected final sample size was estimated to be 30 subjects. However, a total of 60 (30 male and 30 female) participants were included in the study after obtaining written informed consent in accordance with the Institutional Review Board approved protocol after being explained the purpose and procedures in detail.

Multidimensional Fatigue Inventory-20

The Multidimensional Fatigue Inventory (MFI) was used for the assessment of trait exhaustion or fatigue: general fatigue, physical fatigue, reduced activity, reduced motivation, and mental fatigue [22, 23]. The reliability of the MFI-20 questionnaire items was tested using Cronbach's alpha, which was found to be 0.82 indicating MFI as a reliable tool for assessing the subjective fatigue. MFI-20 questionnaire was administered to be answered by the participants before and after the cognitive task performance in both phases to assess the different aspects of exhaustion and to compare any changes in the subjective feeling measures between pre and post the cognitive test (tasks).

P300 Evoked Potential

The P300 is an evoked potential associated to engagement of attention and it is linked to an individual's reaction time to an external stimulus a well as it can be used to measure how demanding a task is on the cognitive workload [24, 25]. In this study ERP data were processed using P300 Standard auditory "oddball paradigm" on fully computerized-evoked potential recorder (RMS EMG MK-2; RMS RECORDERS and MEDICARE SYSTEM Chandigarh) using 10/20 system to know the engagement of attention. Test was carried out in pre-cooled, quiet, dimly lit room with sitting comfortably facing the computer monitor. The acoustically shielded THD 32 ear phones were placed on the ear and head bands were adjusted. Monoaural auditory stimulus consisting of rare faction clicks of 100 microseconds with intensities starting from 30 to 100 dB were delivered through electrically shielded earphones at a rate of 11.1/s. Contra lateral ear was masked. Throughout trial, the participant has to focus attention on one of the 36 characters of the matrix. The random sequence of 6 row and 6 column flashes constitutes an oddball paradigm, with the row and the column containing the desired character constituting the rare set. The thorough description is similar to as described elsewhere [10]. The reaction time measurements were performed when the subject was seated in front of the device and asked to press the button as soon as the light appeared. The RT was measured as the interval of time (ms) between the appearance of the light and pressing the button. The mean value of 5 repetitions was calculated each time and was taken for the analysis.

Description of the Cognitive Tasks

The Stroop test, trial making test (TMT), and Mini Mental State Examination (MMSE) were used as cognitive tasks. These tests place psychological strain of mainly cognitive nature, thereby denuding a sustained attention from participants during entire tasks for them to be accurate and quick in their responses.

A computerized cued *Stroop task* was performed [26]. In this task, an instructional cue is presented on each trial ("word" or "color") and followed by a 1, 3, or 5 s cue-target interval and an imperative color word stimulus ("red," "blue," or "green") written in colored letters. For the "word," the task participants were instructed to read the word, whereas in the "color," task participants were instructed to name the color of the letters. In total, 60% of the trials were congruent (e.g., "red" written in red letters) and 40% were incongruent (e.g., "red" written in green letters).

MMSE was used in quantitatively estimating the severity of cognitive impairment, in serially documenting cognitive change. MMSE was scored as indicated by Folstein et al. [27]. The score is the total number of correct answers where a score of 23 or less generally has been accepted as indicating the presence of cognitive impairment [28].

TMT [29] (or divided attention test) was used to evaluate information processing speed, visual scanning ability, and other cognitive processing and executive functioning performed in 2 parts (A and B). In part A, the participant is given a white sheet of paper with 2 circles on it, numbered 1 through 25, and asked to connect the circles in numerical sequence as quickly as possible. In part B, there are again 25 circles, numbered from 1 through 13 and lettered from A to L, the subject is required to connect the circles, again in sequences, but alternating the letters alphabetically in between. The scores represent the number of seconds required to finish each part.

Procedure

The selected participants were invited at different timings so as to reduce any learning effect (Lord et al. 1998) [30]. The study was conducted in 2 phases with at least a week gap between the phases.

Phase-I (Control Phase)

In this first phase, participants initially completed the MFI-20 questionnaire followed by processing the ERP data using P300 and the performance of cognitive tasks, namely, "Stroop Test, TMT, and MMSE", after which lastly again MFI-20 was administered after the completion of cognition tasks.

Phase-II (Exercise Phase)

In this phase, after initially answering the MFI-20 questionnaire, the participants were instructed to cycle as hard as they could, till they could not continue anymore, which was followed by recording of P300-evoked potential and performance of the cognitive tasks and as in the control phase. Finally after completing the cognitive tasks, they again filled the MFI-20 questionnaire.

Statistical Analysis

The results are expressed as mean ± SD or percentages. SPSS software version 19.0 (SPSS Inc., IBM Corporation, Chicago, IL, USA) was used for analysis. Paired *t test* was used to compare between any dependent variables for significant differences. $p < 0.05$ was considered significant.

Results

The results are described in separate sections namely the subjective measure consisting of the MFI-20 assessing the general fatigue, physical fatigue, mental fatigue, reduced motivation, reduced activity; ERP analysis results followed by the cognitive performance of the participants in terms of both reaction time and percentage accuracy of responses.

MFI-20 Subjective Measures

Fatigue-related subjective measures (MFI-20) showed that both mental and physical exhaustion were significantly greater in the exercise-phase cognitive trial than in the control phase. Table 1 observes the summarized results of the each subjective measures before and after the performance of cognitive tasks, and a significant difference was observed between the means for post control and post exercise experimental condition ($p < 0.05$).

P300 Event-Related Potentials and Cognitive Performance

Lower P300 latencies reflect faster reaction time, but their response accuracies were poorer resulting in poorer cognitive performances (Fig. 1, 2).

The mean reaction time (Table 2) of the participants in responding to the visual cues during the cognitive task for the control phase and exercise phase was 470 ± 19.1 and 405.2 ± 16.2, respectively, which was found to have a statistically significant difference ($p < 0.001$). The participants performed better in the control phase with a mean percentage accuracy of 93.4 ± 2.1 (in %) as compared to accuracy of response performance of 88 ± 1.3 (in %) after exercise cognitive phase but with slow reaction time.

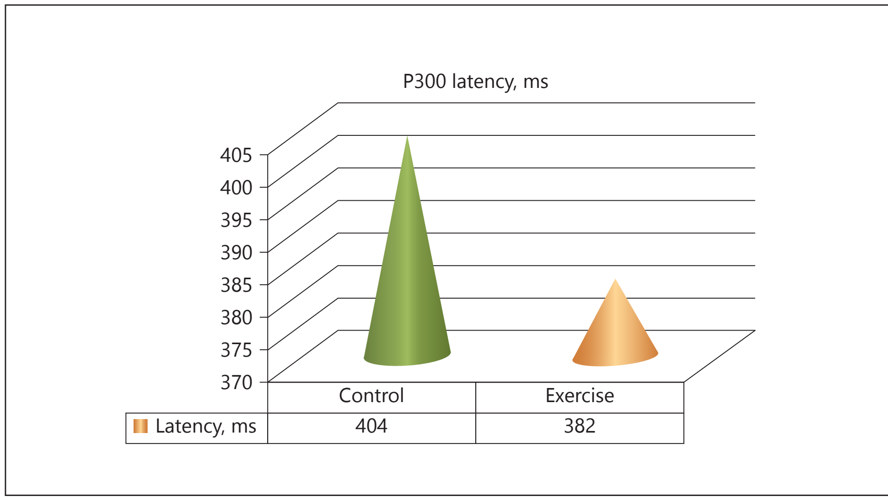

Fig. 1. P300 latencies differences in study participants in control and exercise phase.

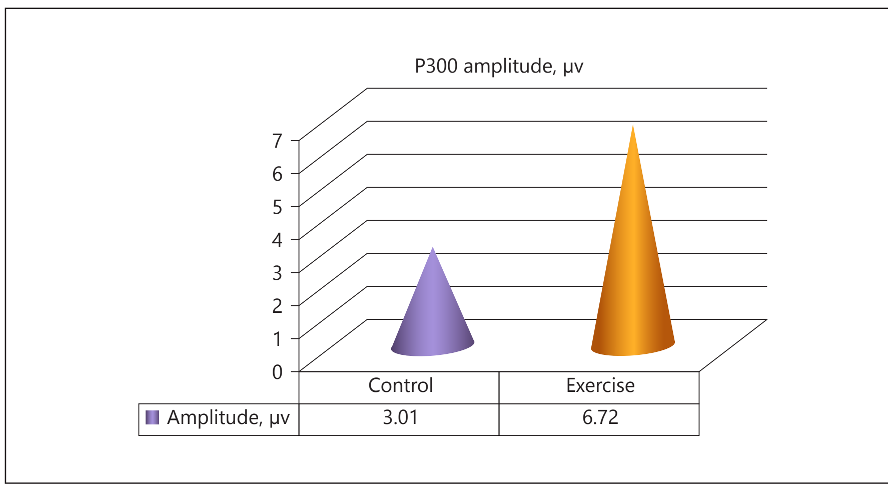

Fig. 2. ERP-P300 amplitude differences in study participants in control and exercise phase.

Table 1. Exhaustion characteristics of the participants under control and exercise phase prior to (Pre) and after (Post) performance of the cognitive test

MFI-20	Control phase, mean ± SD		Exercise phase, mean ± SD	
	pre	post	pre	post
Mental exhaustion	4.3±1.5*	11.3±1.8†	7.4±2.2*	14.8±2.9†
Physical exhaustion	5.7±2.1*	7.1±2.6*	12.3±2.7*	15.4±2.3*

* Denotes a statistical significance at $p < 0.01$ between the means of the MFI measures for precontrol and preexercise cognitive tasks.
† Denotes a statistical significance at $p < 0.05$ between the means of the MFI measures for postcontrol and postexercise cognitive tasks.
MFI, multidimensional fatigue inventory.

Table 2. The cognitive performance of the participants in terms of reaction time and percentage accuracy

Cognitive tasks	Control trial, mean ± SD	Exercise trial, mean ± SD	*p* value
Reaction time	470±19.1	405.2±16.2	<0.001
Accuracy, %	93.4±2.1	88±1.3	0.236

Discussion

The present study showed the mental and physical exhaustion of the participants were significantly more in the exercise phase cognitive tasking. Interestingly, the participants subjected to the exercise involved cognitive tasking had an overall lower mean reaction time as compared in the control phase. Previous research assessing the relationship between cognitive tasking and reaction time has observed a similar findings after a medium or long duration physical task performance [8, 9, 13].

The current study showed that the participants were more accurate in their responses during the control phase than in the exercise phase cognitive test tasking. Lorist et al. [24] showed that increase in fatigue leads to decreased percentage accuracy in response which is in agreement with our study [23]. The P300 component mean amplitude was comparatively greater, and its corresponding latency was smaller after the exercise trial than in the control phase, which indicates the participants reached a faster and higher attention state in the exercise trial than in the control phase. The observations were in agreement with that of similar study conducted elsewhere [31]. The P300 amplitude increased following an exercise; however, other researchers have found that P300 amplitude increase is also influenced by mental fatigue [32].

Exercise improves the blood supply to the brain, leading to improved performance in various cognitive tests. Physical activity is related to changes in the brain through overall cardiovascular conditioning, and it enhances cerebral blood flow and oxygen supply to neurons [33]. Chronic exercise is found to be associated with an improvement in spatial memory and positive cholinergic effects [17]. In any case, it is apparent that even a single bout of moderate intensity exercise can bring about an improvement in cognition, and we believe that this is very important, as aerobic exercise could have a dual benefit, both for physical and mental health [18–21]. It is an already established fact that chronic exercise definitely benefits cognition. However, it is an interesting incentive for the subject to note that there is an improvement in cognition with even a single bout of exercise.

Conclusion

Within the limits of the present study, participants experienced more physical and mental exhaustion during the exercise that involved cognitive tasks. Lower P300 latencies reflect faster reaction time, but their response accuracies were poorer resulting in poorer cognitive performances. An apparent decrease in attention based on decreased percentage accuracy of response was evident. Participants subjected to control trial performed better in terms of higher percentage accuracy but with slow reaction times than after subjecting for exercise-induced exhaustion. This implies that exhaustion, performance, and attention are interdependent, and one should work harder to sustain performance levels that would intensify the development of fatigue.

Disclosure Statement

Authors have no competing financial interests.

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The authors have no funding to declare.

Author Contributions

A.B.H.I. and N.A.P.: conceptualized the paper, S.K.R. and R.S.P.: drafted the paper, and R.K.K., A.B.H.I., and S.A.: edited it.

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