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# Does acute aerobic exercise augments perceptual sensitivity during vigilance task performance?

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The relationship between arousal and attention has become matter of concern in the field of cognitive science. Physical exercise has been recognized as one of the best method to experimentally influence the arousal state among individuals in cognitive studies. The present study was an effort to examine the effects of different arousal levels induced through exercise on vigilance task performance. A 2 (Event Rate: Low and High) ×3 (Exercise protocol: No exercise, mild and intense exercise) ×4 (Time Period: Four 10 minutes block) mixed factorial design with repeated measure on last factor was employed. Ninety healthy male students within age range from 19 to 25 years were assigned into six different experimental conditions and were assessed on forty minutes vigilance task. Perceptual sensitivity scores were computed as recommended from signal detection theory. Repeated measure analysis of variance (ANOVA) revealed least decrement in perceptual sensitivity across time periods under low event rate condition ($p = 0.04$). In addition, mild exercise protocols also reported least decrement across time periods than no exercise and intense exercise, ($p = 0.05$). These findings suggested that optimum level of arousal facilitates vigilance task performance across time periods.

**Keywords:** Arousal, Event-rate, Exercise, Vigilance, Perceptual Sensitivity

Physical exercise has been linked to better physical fitness, brain functioning and cognitive performance (Chaddock, Pontifex, Hillman, & Kramer, 2011; Sibley & Etiner, 2003). It can be categorized into two general metabolic pathways that support the energy to the muscle (i.e. aerobic and anaerobic). Aerobic exercise comprises those activities which require more oxygen than sedentary behavior, whereas anaerobic exercise is short in duration and requires a breakdown of energy sources in the absence of sufficient oxygen. Physical exercise has both chronic and acute effects on cognitive/ brain functioning, the chronic effects of exercise is concerned with the repetition of exercise bouts over time lasting from weeks to years, whereas acute effects refers to its immediate effects on cognitive functioning as soon after an individual stop exercising.

Acute exercise has been hypothesized to alter brain function which affects the mental resources dedicated to cognitive performance (Audiffren, 2009). Researches have well established that maintaining physically activity protects brain from inevitable decay (Erikson & Kramer, 2009; Erickson et. al., 2011). Physical exercise seems to improve cognitive performance on some cognitive tasks under certain circumstances, it also appears to inhibit cognitive performance on other tasks or on the same tasks under diverse conditions. Moreover, the effect of physical exercise on cognitive performance is a broad research area, including multiple domains of human cognitive performance (Churchill, Galvez, Colcombe, Swain, Kramer, & Greenough, 2002; Coteman & Berchtold, 2002; Erikson & Kramer, 2009; Erickson et. al., 2011).

Several researches on the relation between physical exercise and cognitive performance have tested predictions drawn from “arousal” theories (e.g., Hockey, Gaillard,

& Coles, 1986; Humphreys and Revelle, 1984; Kahneman, 1973; Yerkes and Dodson, 1908). Culmination to these theories is the assumption that cognitive performance is dependent on the allocation of energetically resources to meet task demands. Researchers have investigated the effect of physical exercise on cognitive function during and following physical exercise interventions with a prior expectation that exercise intervention will induce state of arousal or fatigue in individuals.

In recent years, attention and arousal level has become the matter of concern in the area of cognitive science and number of studies using psychological or physiological approaches to investigate this relationship. Cognitive scientists have tried to examine possible effects of arousal state on attention and have used various psychological and physiological approaches (Ashby & Isen, 1999). Arousal is a general state of central nervous system reflecting the neural activity, which refer to organism's disposition to react with varying degrees of energy or force (Lang, Bradley & Cuthbert, 2008). Several studies have used neuroelectric approaches for better fundamental understanding of physical exercise and its effects on brain function (Hillman, Snook, & Jerome, 2003; Hillman, Kamjio, & Pontifex, 2012; Scudder, Drollette, Pontifex, & Hillman, 2012). Gutmann, Mierau, Hülsdünker, Hildebrand, Przyklenk, Hollmann, and Strüder (2015) observed improved alpha peak frequency (iAPF) among individuals following physical exercise, which is considered to be a recognized marker of arousal and attention (Jann, Koeing, Dierks, Boesch, Federpiel, 2010). Alpha peak frequency is also positively correlated with information processing and efficiency (Klimesch, 1999). The studies based on event-related potential (ERP) have also reported improved P3 amplitude and shorted P3 latency following aerobic exercise (Kamijo, Nishihira, Higashiura, & Kuroiwa, 2007; Kamijo, Hayashi, Sakai, Yahiro, Tanaka, & Nishihira, 2009; Nakamura, Nishimoto, Akamatu, Takahashi, Maruyama, 1999). P3 has been accepted as primary ERP component, P3 amplitude is believed to reflect better attentional resource allocation dedicated to the particular task (Chang, 2016; Polich, 2007; Wickens, Kramer, Vanasee, & Donchin, 1983), whereas P3 latency is associated with speed of detecting and assessing the stimuli (Chang, 2016; Magliero, Bashore, Coles, & Donchin, 1984; Polich, 2007). Increased P3 amplitude and shortened P3 latency also represents the better amount of resource allocation and stimulus evaluation, respectively. Therefore, in the light of these reported findings it can be concluded that aerobic exercise may lead to greater resource allocation and better information processing and stimulus evaluation on cognitive tasks. Additionally, some other studies have provided evidences that intense exercise also induces fatigue in the brain neurons involved in the central motor drive (Amann & Dempsey, 2008; Gandevia, 2001), which may also lead to performance degradation on cognitive tasks. According to the narrative and meta-analytic reviews (Chang, Labban, Gapin, & Etnier, 2012; Lambourne & Tomporwski, 2010; Tomporwski, 2003) the influence of physical exercise on cognitive performance depends on intensity, medium of intervention and duration of physical exercise.

Sustained attention or vigilance refers to the observer's ability to maintain and preserve their focus of awareness and remain alert to intended stimuli for extended period of time (Davies & Parasuraman, 1982). According to Johnson and Proctor (2004), it is a state of readiness to detect and respond to infrequent and randomly occurring events. The capacity to remain vigilant over time period is critical for many daily tasks. Perceptual sensitivity is a derived measure of vigilance task performance through signal detection theory, which is also termed as d-prime (d'). It specifies the sensitivity of a given observer and as such, reflects the observer's ability to discriminate signals from noise (Dember & Warm, 1979). In general, the higher is the difference between signal and noise distribution, the better is the capability to differentiate non-targets and targets. The typical finding of vigilance research is the decrement in performance over time periods. Number of theories has tried to explain this decrement function. Arousal theory draws on the 'inverted-U' model of arousal proposed by the Yerkes and Dodson (1908). Further the most recognized form of this theory was presented by Hebb (1955). According to this theory, an observer's level of vigilance performance depends on their arousal level. If the arousal level is optimum, then performance improves and if too low or high then performance deteriorates. According to Ashby, Valentin and Turken (2002) physical exercise is a best possible way for experimentally influencing the state of arousal in cognitive studies. Therefore, the present study was designed to examine the effects of exercise induced arousal on vigilance task performance. It was hypothesized that exercise induced arousal would facilitate vigilance task performance.

## Method

### *Participant*

Ninety male students within the age range of 19 to 25 years with mean age (M = 20.83years; SD =01.73) mean weight (M = 61.32kg; SD =10.21) mean height (M =168.93cm; SD =06.31) participated in the study. Participants were randomly assigned into six experimental conditions, (n = 15) in each condition (i.e., no exercise, mild and intense aerobic exercise with low and high event rate). Participants, who had no history of medical condition like asthma, cardiovascular disease and any known brain injuries were included in the study. Physical fitness of the participants was determined by their Body Mass Index (BMI) as recommended by World Health Organization. Only physically fit participants with BMI of 19 to 24 (M =21.63; SD =02.21) were included in the study. All participants had normal (6/6) or corrected to normal (6/9) visual acuity.

### *Apparatus*

An Acer computer (Machine 8/N Verlton with i3 intel processor) with 15" monitor was used for the presentation of stimuli. The sensory vigilance task was developed on SuperLab® (Cedrus, 1992, Version 4.0) software. Medicaid CardiVision Treadmill (Medicaid Systems, Chandigarh, India) was used for exercise (i.e. mild and intense exercise).

### *Experimental Task*

Vigilance task comprised of two squares of different sizes, used as target (3.30 cm2) and non-target (3.00 cm2). The participants were instructed to detect target (big square) over non-target (small-square) and to respond immediately by pressing a designated key on response pad. All stimulus were displayed at the center of the monitor screen. The display of task trial started with fixation (+ sign) for 500 milliseconds, then target or non-target were displayed for 100 milliseconds followed by a blank response screen displayed for 1400/3400 millisecond as per experimental conditions. The target and non-target were kept in 20:80 ratio. There were two experimental task conditions namely high and low event-rate comprising of 30 events/minutes and 15 events/minutes, respectively. The flow chart of vigilance task is displayed in Figure 1.

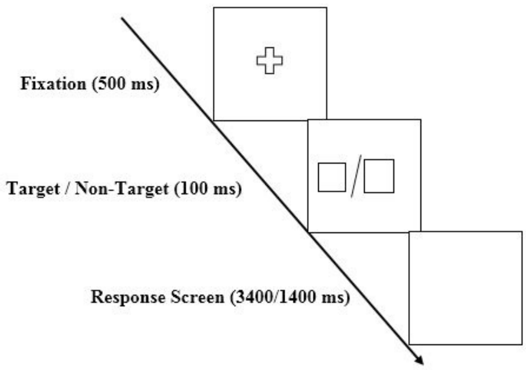


**Figure 1: Flow chart of sensory vigilance task**

### *Experimental Design*

A 2 (Event Rate: Low and High) ×3 (Exercise protocol: No exercise, mild and intense exercise) × 4 (Time Period: Four 10 minutes block) mixed factorial design with repeated measure on last factor was used. Complete details of mild and intense aerobic exercise protocols are presented in Table 1. Event rate (i.e. low and high) and exercise protocols (i.e., no exercise, mild and intense exercise) were treated as independent variable while vigilance task performance in terms of perceptual sensitivity were dependent measure.

**Table 1. Details to mild and intense aerobic exercise protocols**

| | Mild Exercise | | | Intense Exericse | | |
|---|---|---|---|---|---|---|
| Stages | Time (min) | Speed (km/h) | Elevation (%) | Time (min) | Speed (km/h) | Elevation (%) |
| Stage 1 | 1 | 1.5 | 00 | 2 | 1.5 | 00 |
| Stage 2 | 1 | 2.7 | 10 | 2 | 2.7 | 10 |
| Stage 3 | 1 | 3.7 | 12 | 2 | 3.7 | 12 |
| Stage 4 | 1 | 4.2 | 14 | 2 | 4.2 | 14 |
| Stage 5 | 1 | 5.8 | 16 | 2 | 5.8 | 16 |
| Stage 6 | 1 | 6.4 | 18 | 2 | 6.4 | 18 |
| Stage 7 | 1 | 7.8 | 20 | 2 | 7.8 | |

### *Procedure*

Prior to the experiment all the participants were asked to fill biographical information and informed consent were obtained, after that they were allowed to relax for 30 minutes. Participants were randomly assigned into six different experimental conditions with fifteen participants in each group. All participants received three minutes demonstration followed by ten minutes practice of vigilance task. Under intense exercise protocol condition, two groups of participants exercised on treadmill for 14 minutes while the other two groups of participants under mild exercise protocols condition, exercised for 7 minutes and two remaining groups of participants took rest for ten minutes. After performing exercise all participants were given mandatory rest for ten minutes. Subsequently all groups performed on a 40-minute vigilance task.

### *Data Analysis*

Participants' perceptual sensitivity performance on vigilance task was calculated as recommended from signal detection theory (Green & Swets, 1974). Perceptual sensitivity reflects a combination of each participant's average percent targets correct detection (hits) and incorrect detection (false alarms). A 2 (Event Rate: Low and High) × 3 (Exercise protocol: No exercise, mild and intense exercise) × 4 (Time Period: Four 10 minutes block) mixed model analysis of variance (ANOVA) compared participants perceptual sensitivity scores. Statistical models were adjusted for sphericity and Greenhouse-Geisser correction were made for comparisons. The 0.05 alpha was selected as the threshold of statistical significance.

## Result

There was no change in perceptual sensitivity scores under two different event-rate conditions, $F(1, 84) = 3.04$, $p = 0.08$, irrespective of aerobic exercise. However perceptual sensitivity under event-rate differed across four 10 mins blocks of

**Table 2. Mean and standard deviation on perceptual sensitivity as function of event-rate and time periods, irrespective of aerobic exercise**

| Experimental Conditions | | | | | |
|---|---|---|---|---|---|
| | Block 1 | Block 2 | Block 3 | Block 4 | Total |
| Low Event-Rate | 3.03 ± 0.00 | 2.93 ± 0.74 | 2.73 ± 0.91 | 2.70 ± 0.87 | 2.85 ± 0.81 |
| High Event-Rate | 2.88 ± 0.73 | 2.48 ± 0.79 | 2.53 ± 0.84 | 2.41 ± 0.80 | 2.58 ± 0.80 |

**Table 3. Mean and standard deviation on perceptual sensitivity as function of aerobic exercise and time periods, irrespective of event-rate**

| Experimental Conditions | Block 1 | Block 2 | Block 3 | Block 4 | Total |
|---|---|---|---|---|---|
| No Exercise | 2.92 ± 0.71 | 2.62 ± 0.87 | 2.51 ± 0.87 | 2.54 ± 0.95 | 2.65 ± 0.88 |
| Mild Exercise | 2.86 ± 0.61 | 2.79 ± 0.74 | 2.79 ± 0.86 | 2.66 ± 0.83 | 2.78 ± 0.76 |
| Moderate Exercise | 3.08 ± 0.77 | 2.70 ±0.80 | 2.60 ± 0.78 | 2.48 ± 0.78 | 2.72 ± 0.81 |

testing, F (2.88, 242.21) = 2.72, p = 0.04. Mean results under different event-rate condition are presented in table 2 and graphically displayed in figure 2. Results further revealed no change in perceptual sensitivity scores under different exercise protocol conditions, F (2, 84) = 0.22, p = 0.80, irrespective of event-rate. Moreover, perceptual sensitivity scores under aerobic exercise differed across four 10 mins blocks of vigilance testing, F (5.76, 242.21) = 0.70, p = 0.05. Mean results under different aerobic exercise conditions are presented in table 3 and graphically displayed in figure 3. In addition, the results further revealed no change in perceptual sensitivity scores among event-rate × aerobic exercise, F (2, 84) = 0.29, p = 074, nor there were any significant interaction between event-rate × aerobic exercise × time periods, F (5.79, 242.21) = 0.70, p = 0.63.

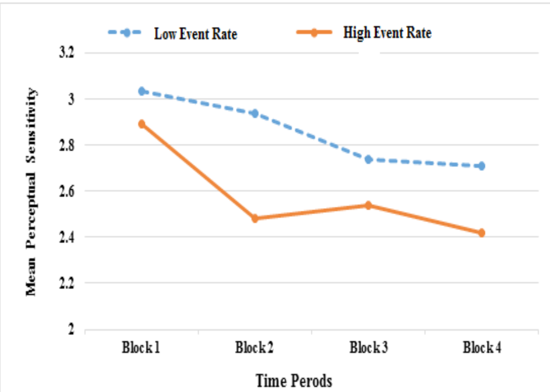


**Figure 2: Perceptual sensitivity as function of event-rate and time periods**

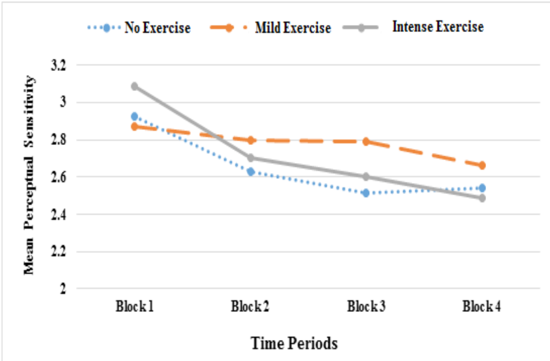


**Figure 3: Perceptual sensitivity as function of aerobic exercise and time periods**

## Discussion

The current study investigated the effects of event rate and levels of aerobic exercise on vigilance task performance. The results revealed that participant's perceptual sensitivity scores did not differ significantly under two different event-rate conditions. However, perceptual sensitivity scores differed across time periods under two different event rate conditions. Higher decrement in perceptual sensitivity across time periods have been observed under high event-rate condition. These findings are consistent with traditional response pattern under vigilance task performance and supported by number of studies. Parasuraman and his associates claimed that high event-rate vigilance task capacity is draining than low event rate tasks, which leads to more decrement in performance. Moreover, resource theory also claimed that operators consume bodily resources at quicker rate than they can be replenished (Kahneman, 1973; Parasuraman, Warm, & Dember, 1987).

The results further revealed that perceptual sensitivity scores did not differed under different exercise conditions, however, perceptual sensitivity scores differed across time periods under different exercise conditions. Participants reported lowest decrement in performance across time periods under mild exercise condition than no exercise and intense exercise condition. The least decrement in perceptual sensitivity across time period under mild exercise can be explained in terms of arousal theory of Yerks and Dodson (1908) which stated that optimum level of arousal is beneficial for performance and exercise protocols were also with prior expectation that it will induce a state of arousal among individuals. According to Easterbrook's (1959) early cue utilization theory a moderate intensity exercise could improve cognitive performance, whereas intense intensity exercise may lead to decrement in cognitive performance. The theory claims that moderate intensity exercise leads to optimum arousal of central nervous system, as the arousal rises, only relevant cues are processed. Accordingly, if the arousal further increased the relevant cues may be missed, which leads to narrowing of attentional performance.

It has been observed that exercise alter brain functions that are dedicated to perform cognitive tasks (Audiffren, 2009). Increased alpha peak activity (iAPF) among individuals following exercise is also evident in number of studies (Gutmann, et. al., 2015), which is a putative marker of better arousal and attention in individuals (Jann, Koeing, Dierks, Boesch, & Federpiel, 2010) and positively correlated with information processing efficiency (Klimesch, 1999). In addition, increased P3 amplitude and shorted P3 latency is also observed following physical exercise in several ERP studies (Chang, 2016; Magliero et. al., 1984; Polich, 2007; Wickens, et. al., 1983), which is a recognized marker of greater resource allocation and faster evaluation of stimulus (Chang, 2016). Contrarily, several other studies have given evidences that intense exercise also induces fatigue in the brain neurons involved in central motor drive (Amann & Dempsey, 2008; Gandevia, 2001), which may lead to performance degradation on cognitive tasks. Mild intensity aerobic exercise protocols were with prior expectation that it will lead to optimum level of arousal among participants, thus the least decrement across time periods in perceptual sensitivity scores was manifested under mild exercise condition.

Results also showed no significant interaction in perceptual sensitivity scores between event-rate and aerobic exercise nor the interaction between event-rate, aerobic exercise and time periods was found significant. The performance difference under event-rate conditions are attributed to degradation of bodily resources and extra inhibition, habituation under high event rate, whereas the performance difference under different physical exercise condition are accredited to temporary changes in the brain functions and cortical arousal induced by exercise. Thus, these results are clearly indicative of independent perceptual sensitivity performance under event-rate conditions from aerobic exercise factor and vice-versa. But this interpretation must be viewed tentatively as further research work is required to observe thoroughly how the temporary bodily changes induced by aerobic exercise interacts with low and high demanding vigilance tasks.

## Conclusion

In conclusion, the current study contributes to the literature investigating the acute effects of different intensities of aerobic exercise on vigilance task performance. The seven minutes mild exercise protocols facilitated vigilance performance across time periods in terms of perceptual sensitivity. The findings support Easterbrook's early cue utilization theory and Yerks and Dodson's optimum arousal model. The findings may be applied in the areas of sports performance, emergency medical room, and military combat operations etc. Several factors limit the interpretation of the present study. Possible gender effects may influence results differently as the present study included only male participants. Future investigation should also include the different nature of vigilance task (cognitive / sensory or successive / simultaneous). Aerobic fitness of individuals may be a significant factor to influence the arousal level through exercise, therefore future examination should also measure the aerobic fitness of participants thoroughly with the help of physiological measures (e.g. VO2max , Heart Rate, Body Temperature etc.). Irrespective of the abundance of the researches on the effects of physical exercise on cognitive performance, issues of aerobic fitness, intensity of physical exercise and its effect on human performance remains largely unsettled. Perfection in the understating of the relationship between physical exercise and cognitive performance may require fine evaluation of aerobic fitness of participants, intensity and duration of physical exercise.

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