NeuroRegulation

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Effect of High-Intensity Intermittent Exercise on Cortical Hemodynamic Changes in Response to Recognition Memory and Visuospatial Tasks

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Abstract

We investigated the acute effects of high-intensity intermittent exercise (HIIE) on cortical hemodynamic changes and sex differences during recognition memory and visuospatial tasks. Forty-six healthy adults (18–30 years) were randomly assigned to HIIE (*n* = 23, including 11 males and 12 females) or control groups (*n* = 23, including 10 males and 13 females). Functional near-infrared spectroscopy measured prefrontal cortex (PFC) activation during Warrington's word and facial Recognition Memory Test (RMT), and Shipley-2 test before and after the intervention. HIIE resulted in improved word recognition memory scores, but no significant changes in face recognition or visuospatial scores. PFC activation during tasks did not significantly differ following HIIE. Sex differences were observed, with males showing greater word recognition memory scores and associated hemodynamics compared to females, but no sex differences in face recognition or visuospatial tasks in response to HIIE. In summary, HIIE improved word recognition memory without affecting PFC activation. Moreover, sex differences in PFC activation during word recognition tasks were evident following HIIE. These findings contribute to our understanding of the acute effects of HIIE on cognitive performance and highlight the potential influence of sex on cortical hemodynamics during word recognition memory tasks.

Keywords: recognition memory; visuospatial functions; cortical hemodynamics; prefrontal cortex

Citation: Sathe, P. K., Shenoy, S., & Sathe, A. (2024). Effect of high-intensity intermittent exercise on cortical hemodynamic changes in response to recognition memory and visuospatial tasks. *NeuroRegulation, 11*(3), 242–254. https://doi.org/10.15540/nr.11.3.242

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Reviewed by:
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Introduction

It has been established that exercise yields cognitive benefits. Regular exercise not only improves cognition but also preserves neuroplasticity and prevents neurodegeneration (Berchtold et al., 2001; Bonanni et al., 2022; Cotman et al., 2007; Hillman et al., 2003; Mahalakshmi et al., 2020; Marques-Aleixo et al., 2021). Studies have examined the effects of physical exercise on executive functions (Alves et al., 2012; Bonanni et al., 2022; H. Chang et al., 2017; Y. K. Chang et al., 2012), memory (Hötting et al., 2016), and attention (Alves et al., 2014). Animal studies have demonstrated the positive effects of physical exercise on recognition memory and nonspatial memory (Hopkins & Bucci, 2010), while exercise has also been found to benefit visuospatial ability in elderly individuals (Tsai et al., 2016). However, the number of available studies investigating the impact of exercise on recognition memory and visuospatial functions is limited, and they present conflicting evidence.

This conflict may arise from variations in exercise type (Loprinzi et al., 2021), duration (Zou et al., 2020), exercise intensity (Taverniers et al., 2010), and participants' fitness levels (Wang et al., 2015). A recent study suggests that memory functions are influenced by exercise intensity, with high-intensity exercise demonstrating the greatest benefits (Kovacevic et al., 2020). However, the relationship between high-intensity intermittent exercise (HIIE) and changes in these cognitive functions remains unclear. HIIE involves brief exercise bouts at maximal intensities followed by low-intensity exercise or rest intervals (Boutcher, 2011). Additionally, HIIE has been associated with the maintenance of cognitive health and has shown multidimensional cognitive benefits (Matthews et al., 2009; Tsukamoto et al., 2016). However, the impact of HIIE on recognition memory and visuospatial functions in young adults has yet to be evaluated.

Recognition memory refers to the process of identifying previously encountered objects, events, or faces (Gardiner & Parkin, 1990). It relies on the familiarity of the stimulus being recognized. The stages of recognition memory involve perceiving the stimulus, comparing it to stored data, and generating related verbal and nonverbal responses (Kim et al., 1999). Various types of stimuli can be perceived, including words, faces, objects, and sounds. Emotional associations, such as pleasant or unpleasant perceptions, can enhance this memory (Herbert et al., 2008). On the other hand, visuospatial ability entails perceiving objects and cues in relation to space and the capacity to manipulate or reorganize their spatial arrangement (Mumaw et al., 1984). It involves visualizing and manipulating spatial dimensions. Visuospatial ability enables an individual to visualize an object or image, break it down into components, and then reconstruct it using those components (Mervis et al., 1999), thereby applying this information to interact with the environment (Trojano & Conson, 2008).

Converging evidence from various neuroimaging studies including functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) has revealed specific regions within the prefrontal and parietal cortices that play a role in visuospatial working memory (Herrmann et al., 2005; Spaniol et al., 2009) and recognition memory tasks (Fusar-Poli et al., 2009; Rugg et al., 1999). Cortical activation patterns have been studied through fNIRS studies (Baker et al., 2018) showing activation of prefrontal cortex (PFC) more as compared to parietal cortex. Notably, fMRI-based investigations have shown significant activation in the bilateral dorsolateral (DLPFC) during visuospatial tasks (D'Esposito et al., 1998). Further evaluation is warranted to examine whether the activation patterns of these brain areas are modulated by physical exercise interventions such as acute HIIE.

Recognition memory is typically assessed using Warrington's Recognition Memory Test (RMT) while visuospatial functions can be evaluated using the Block Patterns subset of the Shipley-2 test. The RMT is a convenient memory test that offers advantages such as easy scoring, minimal reliance on verbal responses, and low demands on other cognitive functions like attention, organization, and motor skills (O'Bryant et al., 2003). It is a reliable and valid measure for the assessment of word and facial recognition memory (O'Bryant et al., 2003; Soukup et al., 1999). The Shipley-2 Block Patterns subset, on the other hand, assesses visuospatial abilities and requires participants to mentally manipulate and transform different patterns to complete a design. This test is a reliable and valid test as well (Lodge, 2013). In our study, we employed 24-channel fNIRS to monitor cortical hemodynamic changes over the PFC during recognition memory and visuospatial cognitive tasks. This allowed us to examine the effects of exercise interventions on cortical hemodynamic functions (Kujach et al., 2018). Previous research has shown significant increases in oxygenated hemoglobin concentration, indicating cortical activation, in the left PFC regions during recognition memory retrieval (Kubota et al., 2006), and physical exercise has been shown to enhance cerebral cortex activation (Endo et al., 2013). However, the specific impact of HIIE on these activation patterns in the cerebral cortex during recognition memory and visuospatial functions has yet to be investigated.

Evidence from the previous literature indicates presence of sex differences in memory functions (Loprinzi & Frith, 2018), with females exhibiting better performance on recognition memory tasks compared to males (Coleman et al., 2018). Nagamatsu et al. (2012) previously demonstrated that 6 months of twice-weekly aerobic exercise training significantly improved executive functions in cognitively healthy women 65 to 75 years old. Sex difference and the type of exercise regime moderates the role of exercise intervention in changing the cognitive performance (Barha et al., 2017). Regular walking activity has been shown to be associated with large volume of posterior hippocampus in females only (Varma et al., 2016). Similarly, sex differences have been observed in spatial cognitive functions and their associated cortical activation (Bao et al., 2022; Munion et al., 2019). However, sex difference in the effect of acute exercise intervention on cognitive changes and their associated brain activation pattern has not been explored. Further, no specific study has examined the impact of acute HIIE on recognition memory, visuospatial functions and their associated cortical activation in a sex-specific manner.

While specific cognitive abilities may vary with age, studying young adults can provide insights into fundamental mechanisms underlying cognition that are applicable to other age groups. Hence, young adults were chosen as the participants of this study.

We hypothesize that there will be a significant difference in the scores of recognition memory and visuospatial functional tasks following HIIE. Additionally, we expect an increase in PFC activation during the performance of these tasks in response to HIIE. Thus, the primary objective of our study was to assess recognition memory and visuospatial functional task scores, as well as the associated hemodynamic response of the PFC before and after the HIIE intervention. Furthermore, our secondary objective was to investigate potential sex differences in the scores of recognition memory and visuospatial functions, along with the related PFC activation, in response to HIIE among young adult males and females.

Methods

Participants

The study utilized a randomized two-group pre–post experimental design. A priori power analysis was conducted using G*Power software (version 3.1.9.4, Germany), with medium effect size (0.5), alpha probability error margin of 0.05 and 80% power of the test. This analysis provided a total sample size of 42. To reduce the likelihood of type-I error, a sample size of 46 (more than the calculated sample size) was taken for further analysis. Thus, a total of 46 healthy adults aged between 18 and 30 years volunteered for the study. They were randomly assigned to either the HIIE group (n = 23, including 11 males and 12 females) or the control group (n = 23, including 10 males and 13 females) using lottery method of simple random sampling. The testing protocol was thoroughly explained to all participants, and written informed consent was obtained from each individual. Table 1 provides details of the participants' meanage, height, weight, BMI, resting heart rate, and physical activity levels. The HIIE group underwent the intervention, as described in the subsequent methods section, while the control group was instructed to rest in a seated position for duration similar to the HIIE session. Participants provided written informed consent before the initiation of the testing procedures. The study received approval from the Institutional Ethics Committee of Guru Nanak Dev University, Amritsar (approval number 158/HG, dated 1 October 2019).

Study Criteria

University students with normal or corrected normal vision and no color blindness were selected for participation. They were matched based on their IQ using the Multidimensional Aptitude Battery-II (MAB-II). Participants were instructed to consume only one cup of tea or coffee before each testing session, following the breakfast instruction sheet provided during their initial visit to the laboratory. On their first visit, they were also given the International Physical Activity Questionnaire (IPAQ) for the assessment of level of physical activity during the past week (Papathanasiou et al., 2010), Physical Activity Readiness Questionnaire (PARQ) for ruling out any cardiac, respiratory, or neurological history before the exercise testing (Agarwal et al., 2016), and Pittsburgh Sleep Quality Index (PSQI) to assess the sleep quality in the past one month (Pilz et al., 2018).

Inclusion criteria consisted of healthy male and female participants between the ages of 18 and 30, with an IQ ranging from 90 to 119 as measured by the MAB-II. Exclusion criteria included answering "yes" to any of the PARQ questions, having a history of cardiorespiratory or cerebrovascular disease, having a psychiatric or neurological condition, engaging in strenuous activity, or consuming alcohol within 24 hr prior to testing, experiencing poor sleep (as measured by the PSQI), consuming two or more cups of caffeine on the same day, or consuming a large meal within 2 hr before exercise.

Exercise Protocol

HIIE protocol of four bouts of 4 min (4*4) at 90–95% HR max with 3 min of active recovery at 70% HR max (Helgerud et al., 2007) interspersed with the intense bouts on a cycle ergometer (Lode Corival BV, Groningen-The Netherlands) was applied. Polar heart rate monitor (Polar Vantage V Pro Multisports Watch) was used to monitor heart rate during the whole exercise session. HR max (beats/min) was calculated by the formula (Fox et al., 2013).

$$\text{HR max} = 206.9 - 0.67 \times \text{age (year)}$$

Figure 1. *Study Design*.

Day 1	Familiarization session of the cognitive tests, breakfast instruction, IPAQ questionnaire, PSQI questionnaire, MAB-II questionnaire. Participant recruitment in either of the two groups.
Day 2	Pre data recording (RMT with fNIRS and Shipley-2 test with fNIRS)
At least 1 week after the pre data recording	HIIE intervention and same day post data recording (RMT with fNIRS and Shipley-2 test with fNIRS)

Note. The above figure describes the study design and the timeline used for the procedure of the study. IPAQ – International physical activity questionnaire; PSQI – Pittsburgh Sleep Quality Index; MAB-II – Multidimensional Aptitude Battery-II; RMT – Recognition memory testing; fNIRS – functional near-infrared spectroscopy; HIIE – High-intensity intermittent exercise.

Participants cycled against a workload of 100–150 W at an average rate of 120 RPM and between 15 and 18 on Borg's Rating of Perceived Exertion (RPE) scale during each high-intensity bout and, with no workload, an average 91 RPM and 8–12 Borg's RPE during the recovery period. Borg's RPE was noted after 1 min of start of high-intensity bout and after the end of each of the four high-intensity bout sessions. The HIIE protocol was preceded by a 3-min warm-up and followed by a 2-min cooldown, at a pedaling frequency and intensity as per each participant's preference between 8 and 12 grading of the 20-pointed Borg's RPE scale. All the participants were able to complete the whole test with no dropouts. Interparticipant variations were seen during the exercise intervention because of the high intensity of the exercise, but the whole exercise intervention was well tolerated. All training sessions were conducted in a neurophysiology lab of MYAS-GNDU Department of Sports Sciences and Medicine of Guru Nanak Dev University, Amritsar.

Cognitive Testing

Cognitive functions were assessed using two tests: Warrington's word and face RMT and the Block Patterns test of Shipley-2. The administration order of the tests was counterbalanced between the pre- and postsessions for both groups to eliminate bias. There was a minimum gap of 1 week between the pre and postsessions to minimize the impact of learning on the cognitive tests.

Warrington's Recognition Memory Test (RMT)

This test evaluates recognition memory for both words and faces. The RMT was utilized to assess deficits in material-specific recognition memory. It consisted of two subtests: Recognition Memory for Words (RMW) and Recognition Memory for Faces (RMF). Each subtest included 50 target stimuli displayed for 3 s. Participants were required to rate each stimulus as pleasant or unpleasant, responding with a "yes" or "no" accordingly. Subsequently, participants were presented with each of the 50 target stimuli paired with a distracter and asked to identify the target stimulus by either pointing to it or reading it aloud. The number of correct responses was recorded as raw data for subsequent analysis of accuracy.

Block Patterns Test of Shipley-2

This scale is utilized to evaluate visuospatial ability (Lodge, 2013). It consisted of two parts: Part A and Part B, each containing 12 block patterns. Multiple blocks within a specific pattern were queried, resulting in a total of 26 items to be scored. Part A consisted of simple blocks to be answered, while Part B increased the difficulty level by rotating the blocks to 90 or 180 degrees. Participants were provided with multiple choices to indicate which block option would fit in the gray square within the given block pattern. The number of correct responses for both parts was recorded as raw data for subsequent analysis.

Hemodynamic Testing Using Functional Near-Infrared Spectroscopy

Hemodynamic changes, specifically oxyhemoglobin (oxyHb) and deoxyhemoglobin (deoxyHb) levels in µmol, were measured using the portable Brite Artinis fNIRS (version 24; Artinis Medical Systems, The Netherlands) brain imaging system. The measurements were taken before and after the HIIE sessions, during the cognitive testing. After the intervention, a 6- to 10-min gap was followed, right before the postintervention cognitive and fNIRS assessments. This time interval allowed the physiological artifacts to decline, which are known to be enhanced by an increased heart and respiratory rates (Pinti et al., 2019).

Participants were in a sitting position during the measurements. The purpose of collecting fNIRS data during the RMT and Shipley-2 testing was to examine the hemodynamic changes associated with acute HIIE. To establish a baseline, 10 s of fNIRS data was collected immediately before starting the cognitive tests and also before the HIIE session, as recommended by Fox et al. (2013). During baseline data acquisition, participants were instructed to sit quietly and relax. Post-HIIE data was collected 10 min immediately after the HIIE session.

The fNIRS data was collected using a 24-channel Brite Artinis fNIRS system configured into a 3x3 optode pattern on each lateral side of the PFC, following the topographic probe layout map of the 10–20 International Standard Coordinate system (Herwig et al., 2003; Homan et al., 1987). A soft neoprene cap, selected based on the participant's head diameter, was used to secure the optodes on the participant's head. This configuration provided a total of 24 channels (12 on each side) with an overall emitter and detector separation of approximately 3 cm (Kalia et al., 2018). The channel grids were placed to cover specific regions of interest (ROI) for each hemisphere, including the DLPFC, ventrolateral prefrontal cortex (VLPFC), and frontopolar area (FPA) over the PFC. A differential path length factor was calculated based on the exact age of each participant. A sampling rate of 10 Hz was used, which is consistent with the literature (Yanagisawa et al., 2010)

For the fNIRS data, preprocessing was performed using the open-source software HOMER 2, which is implemented in MATLAB (MathWorks). All recorded signals were initially converted to optical density for processing in the HOMER 2 software. Channels with low amplitudes were excluded from group processing. The signals were then processed using the principal component analysis method to eliminate any systematic artifacts, following the methods described in previous literature (Tak & Ye, 2013). Motion artifacts exceeding a threshold of more than 15 standard deviations from the mean were identified and replaced with spline interpolation based on the preceding and subsequent segments of the signals. Wavelet filtering was applied to remove motion-induced sharp spikes, as suggested by previous literature (Jahani et al., 2018). After this processing, the signals were bandpass filtered within the frequency range of 0.02–0.5 Hz to eliminate baseline drift and physiological noise. Finally, the filtered signals were converted to oxyHb and deoxyHb concentration (µmol) data using the modified Beer-Lambert law (Cope & Delpy, 1988). To infer changes in the hemodynamic response across the participants, a block averaging method was employed.

Statistical Analysis

The cognitive data obtained was subjected to Shapiro-Wilk test in order to determine the normality distribution of the data. An independent sample *t*-test was used to compare the data of the demographic variables of the two groups at baseline. A two-way ANOVA was utilized to evaluate the main and interaction effects, with group (control/HIIE) and session (pre/post) considered as between-subject factors for RMT word, RMT face, and Shipley-2 scores. Two-way ANOVA was also used to analyze main and interaction effect of HIIE on oxy and deoxyHb concentrations with group (control/HIIE) and session (pre/post) as between the subject factors. Three-way ANOVA was used with group (control/HIIE), session (pre/post), and sex (female/male) for the evaluation of sex difference in the cognitive scores and PFC hemodynamics in response to HIIE amongst the participants. Partial η^2 values were used to report the effect sizes for the significant main and interaction effects. Bonferroni's post hoc test was used for pair-wise comparison.

Results

Word Recognition Memory

On two-way ANOVA analysis, we found a significant ($p < .05$) effect of group for the scores of RMT word, $F(1,88) = 4.44$, $p = .034$, partial $\eta^2 = 0.045$; and session, $F(1,88) = 64.98$, $p = .0001$, partial $\eta^2 = 0.35$; and a significant interaction of group*session, $F(1,88) = 13.85$, $p = .0001$, partial $\eta^2 = 0.136$ (Figure 2). These findings indicate an improvement in RMT word scores in response to HIIE intervention.

Face Recognition Memory Scores

RMT face scores showed a significant effect of session, $F(1,88) = 14.25$, $p = .001$, partial $\eta^2 = 0.139$; but no significant effect of group, $F(1,88) = 0.125$, $p = .725$, partial $\eta^2 = 0.001$; and group*session, $F(1,88) = 0.060$, $p = .807$, partial $\eta^2 = 0.001$, was observed (Figure 2). These results show no significant change in RMT face performance in response to HIIE.

Table 1
Demographic Variables of the Participants of Control and HIIE Group

	Control group	HIIE group	*t*-value	*p*-value
Number (*n*)	23	23	-	-
Male: female	10:13	11:12	-	-
Age (years)	23.95 ± 1.36	23.62 ± 1.55	0.762	.450
Height (m)	1.62 ± 0.08	1.63 ± 0.07	−0.534	.596
Weight (kg)	60.46 ± 9.32	60.08 ± 8.74	0.143	.887
BMI (m/Kg^2)	23.00 ± 3.07	22.47 ± 2.27	0.675	.503
Resting heart rate (beats/min)	81.72 ± 2.62	80.37 ± 4.78	1.172	.247
Physical activity level (measured by IPAQ in MET*min / week)	2024.93 ± 1113.95 (Moderate physical activity level)	2400.22 ± 1207.34 (Moderate physical activity level)	−1.093	.281

Note. The above table shows values of variables as mean ± standard deviation.

Shipley-2 Scores

Shipley-2 scores showed a significant effect of session, $F(1,88) = 5.69$, $p = .019$, partial $\eta^2 = 0.057$; but no significant effect of group, $F(1,88) = 3.006$, $p = .086$, partial $\eta^2 = 0.031$; and group*session was observed, $F(1,88) = 0.506$, $p = .478$, partial $\eta^2 = 0.005$. It shows that visuospatial functions were improved in both control as well as HIIE group, but HIIE did not affect the scores of Shipley-2 scale (Figure 2).

Hemodynamic Response to HIIE

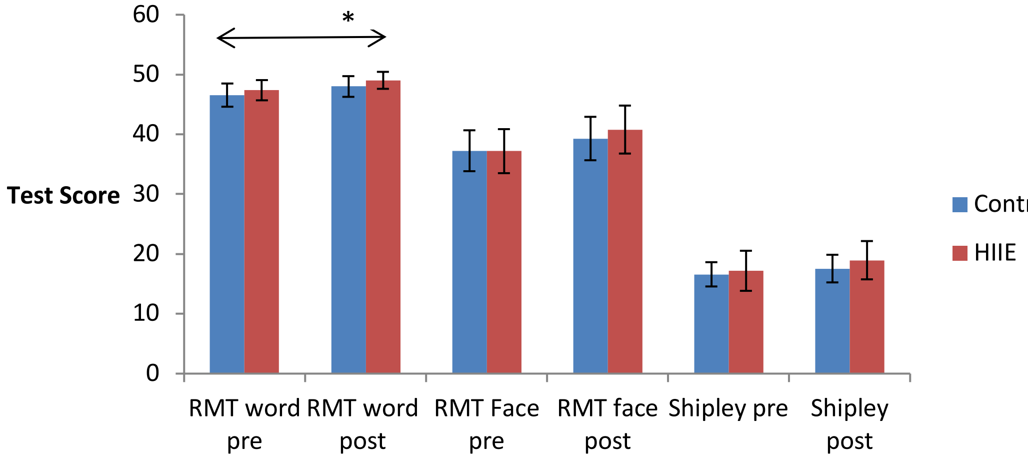
Hemodynamic Response During Warrington's Word and Face Recognition Memory Task. Pre values of oxy and deoxyHb concentration showed no significant difference between the control and HIIE group. A significant difference ($p < .05$) in the oxyHb concentration was observed in the right FPA during both RMT word ($p = .007$) and RMT face test ($p = .039$) in response to HIIE. However, deoxyHb concentration in the right FPA did not show a significant change. Activation of a particular area has been shown as an increase in the oxyHb and a decrease in the deoxyHb concentration (Lachert et al., 2017) and, thus, we cannot state the changes in the activation in response to HIIE in our study.

Hemodynamic Response During Shipley-2 Test. Post mean values of oxyHb concentration during Shipley-2 did not show a significant change in the right FPA and in any other region of interest of PFC in response to HIIE in our study. DeoxyHb concentration also showed no significant difference in response to HIIE in any of the area of interest in the PFC.

Effect of Sex of the Participant on the Cognitive and Hemodynamic Scores in Response to HIIE. A significant effect of sex was observed on word recognition memory scores ($p = .035$) shown in Table 3, with females getting more benefited with HIIE intervention compared to males. No significant effect of sex was shown on face recognition memory ($p = .989$) and Shipley-2 scores ($p = .936$).

We found a significant increase in the activation (an increase in oxyHb and a decrease in deoxyHb) in females during RMT word task in response to HIIE, where no such increase was seen in males in response to HIIE (Table 4). No significant interaction of group*session*sex was observed for oxyHb and deoxyHb concentration in any of the ROI during RMT face and Shipley-2 task, in response to HIIE in our study. It indicates that no significant sex effect of HIIE was present for the PFC activation during the performance of face recognition and visuospatial task.

Figure 2. *Changes in Cognitive Scores in Response to HIIE*.



Note. The above figure shows the variation in the mean scores of recognition memory test scores (RMT face and words) and Shipley-2 scores before and after HIIE session. Error bars represent standard deviation values. * = Indicates a significant difference between pre and post values of RMT word scores in response to HIIE.

Table 2
Changes in Cortical Hemodynamics in Response to HIIE

Test-Associated Hemodynamics	OxyHb Control (mean ± *SD*) (μ mol)	OxyHb HIIE (mean ± *SD*) (μ mol)	*p*-value	Partial η^2 values
RMT word	−9.234 ± 1.19	1.779 ± 0.14	**.007***	**0.326**
RMT faces	−4.988 ± 1.59	1.60 ± 0.06	**.039***	**0.161**
Shipley	−4.810 ± 1.63	1.233 ± 1.21	.104	0.079

Note. The above table presents the difference of post mean values of oxyHb concentration between the control and HIIE group during RMT and Shipley-2 block test in the right FPA region. * = Represents a significant difference at $p < .05$ level of significance.

Discussion

Cognitive Response to HIIE

This study aims to evaluate the effects of HIIE on recognition memory and visuospatial functions, as well as the associated hemodynamic changes. We observed a significant improvement in word recognition memory performance following the acute HIIE protocol. This finding differs from a previous study (Rattray & Smee, 2016) which reported no effect of HIIE on simple recognition memory accuracy in young adults. The disparity in results may be attributed to the difference in exercise duration, as the mentioned literature used a 1-hr protocol compared to our study's 25-min protocol. Longer durations of high-intensity exercise can deplete the body's energy stores and lead to diminished performance. In contrast, our results suggest that HIIE with a shorter duration is effective in enhancing word recognition memory.

The memory process is influenced by various neurotransmitters, including acetylcholine, glutamate, gamma amino butyric acid (GABA), adrenaline, and noradrenaline (Miranda, 2007). Improvement in recognition memory is attributed to changes in the noradrenergic system of brain. Previous studies in humans and in animal models demonstrated noradrenaline mediating recognition memory process by the activation of subcortical structures such as amygdala and hippocampus (Barsegyan et al., 2014; van Stegeren et al., 2005). Improvement in the performance of recognition memory is associated with the increase in the concentration of noradrenaline neurotransmitter in response to acute exercise intervention (da Silva de Vargas et al., 2017; Kitaoka et al., 2010; Kliszczewicz et al., 2017).

Table 3
Warrington's Recognition Memory and Shipley-2 Scores in Males and Females

Group	Control				HIIE			
Session	Pre		Post		Pre		Post	
Sex	Female	Male	Female	Male	Female	Male	Female	Male
RMT Word	46.13 ± 1.99	47.37 ± 1.68	47.53 ± 2.83	46.12 ± 2.41	44.81 ± 1.92	46.13 ± 1.80	**49.00 ± 1.03**	48.42 ± 1.13
RMT Face	36.86 ± 3.77	37.12 ± 3.22	40.86 ± 4.13	38.87 ± 2.28	38.18 ± 3.15	35.71 ± 3.48	41.37 ± 4.37	37.71 ± 4.23
Shipley-2	16.26± 2.21	17.25 ± 3.01	17.53 ± 2.72	17.62 ± 3.08	17.23 ± 1.58	17.11 ± 4.13	19.67 ± 1.40	17.66 ± 3.20

Note. The above table shows mean ± standard deviation of pre and post values of RMT and Shipley test results in males and females of control and HIIE group. Bold value represents a significant difference between pre and post values at $p < .05$ level of significance.

Table 4
Hemodynamic Changes in the Right VLPFC in Response to Word Recognition Task in Males and Females

Sex	Female				Male			
Group	Control		HIIE		Control		HIIE	
Session	Pre	Post	Pre	Post	Pre	Post	Pre	Post
OxyHb (µ mol)	0.139 ± 0.197	0.119 ± 0.10	0.023 ± 0.08	**0.565 ± 0.10**	0.100 ± 0.07	0.043 ± 0.10	0.366 ± 0.08	0.224 ± 0.06
DeoxyHb (µ mol)	−0.282 ± 0.22	0.092 ±0.29	0.509 ± 0.073	**−0.161 ± 0.026**	0.074 ± 0.01	−0.005 ±0.04	0.076 ± 0.005	−0.088 ± 0.029

Note. Bold values indicate a significant difference (at $p < .05$ level of significance) between pre and post values.

Our results of an increase in word recognition memory in response to acute HIIE in young adults are in agreement with these findings.

The enhancement in recognition memory observed in our study suggests a potential influence of changes in the noradrenergic system of the brain. This suggests a potential mechanism through which HIIE affects cortical hemodynamic changes in response to recognition memory tasks, as explored in our study.

We did not find a significant improvement in the performance of facial recognition memory. Facial recognition is a crucial cognitive domain for social interaction. It has been recently studied in depth for its role in security of electronic devices and cyber security. Facial recognition is divided into input, processing, and output stages (Anwarul & Dahiya, 2020). Input phase involves observing the identifying features of the face such as nose, eyes, lips, and cheeks. These features vary on the basis of depth, breadth, and length in the population, and these are very precisely registered in three-dimensional image forms in the brain, when an individual is seen in person. Whereas, by looking at an image of the person, only two-dimensional features are registered in the brain in the input phase. Many factors such as color, resolution, contrast, pose, expression, and light in the image affect facial identification (Sharif et al., 2017), and therefore it is a more difficult task as compared to identifying the person by direct viewing. The next phase comprises of perception of face stimuli by neurobiological mechanism of the brain. This involves several areas of brain such as hippocampus, left prefrontal cortex, inferior frontal gyri, cingulate cortex, and fusiform face area (FFA) situated in the temporoparietal area (Haxby et al., 1996). In the third phase, memory retrieval is done from the stored information in the brain areas and recognition of familiar faces, that engages PFC (Rugg et al., 1999).

Like word recognition, face recognition memory is also mediated by neurochemicals such as oxytocin (Bate et al., 2015). The changes in the facial recognition memory in response to physical exercise are attributed to the changes in the central and peripheral concentration of oxytocin. However, the concentration of this neurochemical is only increased after exercise of longer duration (more than an hour; Hew-Butler et al., 2008) and not by the exercise of lesser duration such as high-intensity continuous exercise of 20-min duration (Gilbert & Loprinzi, 2022). Consistent with these evidences, we did not find a significant difference in the performance of facial recognition memory in our study, attributing to no change in the concentration of oxytocin.

An increase was seen in our study in the post scores of Shipley-2 test, but the effect of intervention on visuospatial scores was not clear because no interaction of sessions with group was seen. The previous literature has shown a positive effect of acute aerobic exercise on visuospatial functions in older adults and in physically fit individuals who exercised regularly; whereas, no significant effect was observed in the lower fitness group (Tsai et al., 2016). The participants of the two groups in our study belonged to the same lower fitness group, having similar IPAQ scores (Table 1) as that of this mentioned study. The findings of no significant effect of acute HIIE in our study were consistent with their results of acute aerobic exercise intervention in the lower fitness group. Fitness level is maintained by a long-term physical activity level, and it has been found to increase processing speed of central nervous system by increasing angiogenesis and blood volume in the cerebral cortex (Swain et al., 2003). Processing speed has a direct correlation with mental rotation skills and visuospatial ability (Heppe et al., 2016). Thus, it can be postulated that long-term physical activity training would be associated with a greater visuospatial performance. However, we used intervention with only one session to look for these effects in the central processing-related visuospatial improvements, which was not found significant. It seems that a single session of acute HIIE was not sufficient to raise the performance level of visuospatial ability in young adults. Further research with long-term HIIE training is warranted to look for the same.

Hemodynamic Response to HIIE

A significant effect of HIIE was observed in the change of oxyHb concentration of right FPA during both recognition of words as well as during recognition of faces in our study, but we did not find a significant effect on deoxyHb concentration in the PFC. This indicates no significant change in the activation, as we previously mentioned that activation of any area involves increase in the oxyHb and a decrease in the deoxyHb concentration. Selective response of the PFC has been observed in response to facial recognition in previous studies (Nelson, 2001; Ó Scalaidhe et al., 1999), but the effect of acute exercise intervention on PFC activation during visuospatial functions has not been studied to date. Our study was the first one to evaluate this effect in young adult males and females. However, we did not find a significant change in the PFC activation in response to acute HIIE intervention in our study. Recognition memory functions involve activation of many brain areas such as hippocampal, parahippocampal, and occipital gyrus (Yonelinas et al., 2001). PFC area also plays an important role in the formation of recognition memory (Zhou et al., 2016). Physical exercise has been shown to improve functional connectivity in PFC during recognition memory task in animal models (Dong et al., 2018). Previous research (Friedl-Werner et al., 2020) has shown that a long-term HIIE training program of 5–6 times weekly for a duration of 60 days has shown improvements in the activation of hippocampal area in participants during recognition memory task. Perhaps a single exercise session was not sufficient to raise neural responses in the PFC during recognition memory task in our study, and a prolonged training intervention is required. We also evaluated PFC response during visuospatial functions, and the findings showed that HIIE did not affect the changes in the concentration of oxyHb and deoxyHb of the PFC during visuospatial activity. Further research is needed to identify the cortical neural correlates of recognition memory and visuospatial ability in response to HIIE training protocol.

Sex Difference in the Performance and Neural Correlates of the Cognitive Tasks

We found a significant increase in the activation in both males and females in the right VLPFC in response to HIIE during the performance of recognition memory word task. However, females showed a greater activation compared to males after HIIE. More activation of the right VLPFC during word recognition task in females attributes to a significantly better performance in RMT word scores compared to males in our study. Our findings support previous studies demonstrating a better object recognition memory in women as compared to men after a moderate intensity exercise (Coleman et al., 2018).

No significant sex difference was observed for the activation during the performance of face recognition task, indicating a similar ability to recognize faces in men and women. These results of similar facial recognition memory in males and females and an associated similar activation of PFC are consistent with the findings of similar activation of other brain areas such as amygdale, insula, and hippocampus in men and women, observed in a previous fMRI study (Ino et al., 2010). Our study was the first one to evaluate the sex difference in the effect of HIIE on the facial recognition and its associated prefrontal cortical activation. However, we did not find any significant difference in the same variables.

No difference in the visuospatial task performance and associated PFC activation was observed between males and females in the current study. Men generally outperform women in visuospatial task, which was also shown by a longitudinal study in middle and old-aged adults (de Frias et al., 2006), but our findings were not in agreement with theirs. Similar PFC activation during this task is attributed to the similarity in performance of visuospatial task between men and women in our study.

Conclusion

We conclude that improvement in the word recognition memory occurs in response to HIIE. Face recognition memory remains unaffected by a single bout of HIIE session. Visuospatial ability does not show a significant effect, in response to HIIE. Improvement in the PFC hemodynamics is shown through oxyHb concentration during recognition memory task but deoxyHb concentration remains unchanged in response to HIIE. Effects of a single session of HIIE are not translated to an improvement in prefrontal activation. Word recognition memory shows a greater benefit for women in response to HIIE, as compared to men. No sex difference was found in the scores of face recognition, visuospatial functions, and their associated PFC hemodynamic functions.

Author Disclosure

The authors declare no conflicts of interest. The study was supported by a grant received from Ministry of Youth Affairs and Sports, Government of India. Equipment, tests, and research fellows were all funded by this grant. We thank Mr. Abhishek Sathe for his help with software operations. We thank our participants for taking part in the study.

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Received: February 5, 2024
Accepted: August 5, 2024
Published: September 30, 2024