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Original Article

Physiotherapy Section

Effect of High-intensity Functional Training on Visuospatial Working Memory in Middle-aged Adults: A Pilot Study

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ABSTRACT

Introduction: Visuospatial working memory is a key cognitive domain that shows subtle decline with age. While aerobic exercise has demonstrated cognitive benefits, evidence on the effects of High-intensity Functional Training (HIFT) on Visuospatial Working Memory (VSWM) in middle-aged adults remains limited.

Aim: To evaluate the effect of a 6-week HIFT program on VSWM storage and executive updating in healthy middle-aged adults.

Materials and Methods: The present single-arm pre-post pilot study was conducted at Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana-Ambala, Haryana, India, between August and December 2025. Seventy-two healthy adults (36 males, 36 females), aged 35-50 years, underwent a supervised HIFT (5 sessions/week for 6 weeks). VSWM was assessed at baseline and post-intervention using the Corsi Block-Tapping Task (memory span) and a Visuospatial 2-back task (updating), with sensitivity index (d′) and Reaction Time (RT) as outcome measures. Data were analysed using paired t-test and Wilcoxon signed-rank test with effect size estimation.

Results: The median Corsi span increased from 4.0 to 5.0 ($p<0.001$; $r=0.86$). On the 2-back task, sensitivity (d′) improved from 2.36±0.52 to 2.84±0.48 ($p<0.001$; $d=0.68$), and RT decreased from 612±95 ms to 558±82 ms ($p<0.001$; $d=0.61$).

Conclusion: A 6-week HIFT program was associated with improvements in both storage and executive components of VSWM in middle-aged adults. These findings are preliminary and should be interpreted cautiously due to the single-arm design. HIFT may represent a time-efficient exercise strategy with potential cognitive benefits in middle adulthood.

Keywords: Attention, Cognitive aging, Physical fitness, Prefrontal cortex, Visuospatial memory

INTRODUCTION

The VSWM is an essential cognitive system that is involved in the temporary storage and manipulation of visual and spatial data that is needed in learning, navigation, reasoning and goal-oriented behaviour. VSWM is maintained within the parietal and prefrontal cortical networks and is necessary for everyday functioning, and the higher-order functioning [1,2], and age changes in VSWM have been associated with the deterioration of problem-solving efficiency, task performance and executive control, and it has been shown that age changes may occur at middle adulthood, not in late life [3].

Exercise has been found to cause structural and functional brain changes, such as improved cerebral perfusion, improved synaptic function, and elevation of neurotrophic factors, including brain-derived neurotrophic factor [4,5] which have been associated with memory and executive function. Despite clear evidence of exercise-cognition relationships in children and the elderly population, research on middle-aged populations is scarce and contradictory, especially on domain-specific results, like VSWM [6].

High physical demand with motor coordination and cognitive demand exercise modalities can, possibly selectively, be advantageous to executive and visuospatial domains. Psychological studies in children and adolescents have depicted that training in gymnastics and more complex sports activities is linked to better VSWM, in comparison to sedentary behaviour [7]. Studies in developmental neuroimaging have also provided evidence that VSWM performance and experience-dependent brain plasticity have been linked to the mentioned training [8-11]. Nonetheless, such results cannot be directly projected to middle-aged adults, who are differently neurobiologically endowed, limited in their lifestyles and susceptible to exercise.

Aerobic exercises demonstrated improved working memory and executive functions in aged individuals [12]. Physical activity interventions have been shown to enhance VSWM in patients with mild cognitive impairment and Alzheimer's disease, with the effects of exercise intensity, duration, and modality being important [13]. These results indicate that there is much plasticity in the adult brain, and it can still respond to cognitive stimulation by exercise.

Despite such an increasing body of literature, there is still a visible gap in the research on the impact of high-intensity functional exercise on VSWM among healthy middle-aged adults. The middle adulthood is a phase of transition that is critical and is marked by early subclinical cognitive alterations, diminished physical activity, and escalating occupational demands. Early intervention by modifying lifestyle behaviours, including physical inactivity, at this age can be relevant to mental health and preventing age-related deterioration.

Thus, the current pilot study was designed to test the influence of a 6-week HIFT program on the VSWM storage and executive updating in healthy middle-aged adults. This trial was designed using the study protocol that had been published earlier [14].

MATERIALS AND METHODS

The present pilot study was a pre-post single-arm study that was carried out at Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Maharishi Markandeshwar (Deemed to be University), Mullana-Ambala, Haryana, India, during the period between August and December 2025. The Institutional Ethics Committee (IEC-3461) gave approval of the ethical issue. All the procedures were done according to the Declaration of Helsinki (2013 revision). The trial was registered on Clinical Trials Registry of India (CTRI/2025/10/096419; https://ctri.nic.in).

Inclusion and Exclusion criteria: Adults aged 35-50 years were considered eligible to be included in the current study with normal cognitive ability, i.e., a Mini-Mental State Examination (MMSE) score more than 24, optimal or corrected-to-optimal vision, and had the capacity to comprehend and adhere to study instructions. The MMSE cut-off was chosen with regard to established normative measures of cognitively healthy, adult individuals [12]. The exclusion criteria included the participants who had a history of cardiovascular disease, or had neurological or psychiatric conditions, had undergone surgery in the past six months or were taking drugs that are likely to affect cognitive ability. Those individuals who had musculoskeletal or medical impairments that might constrain high-intensity exercise were also excluded.

Sample size calculation: Sample size calculation followed the standard formula for repeated measures t-tests:

$n=\{Z(1-\alpha/2)+Z(1-\beta)\}^2\times(\sigma^2\times2/\delta^2)/(1-\rho)$, where $Z(1-\alpha/2)=1.96$ for $\alpha=0.05$ (two-tailed), $Z(1-\beta)=0.84$ for 80% power, $\sigma=1.2$ represents typical Corsi span standard deviation from normative data [15], $\delta=1.0$ span unit reflects expected HIFT improvement based on HIFT literature [16-18], and $\rho=0.5$ accounts for pre-post correlation.

This calculation yields approximately 30 participants. Applying a conservative 20% attrition buffer increases the target to n=36. The recruited sample of 72 participants (36 males, 36 females), providing capacity for subgroup analyses by sex, enhanced precision in effect size estimation beyond pilot study minimums [19,20], and robustness against higher-than-expected dropout rates common in exercise intervention trials.

Study Procedure

The convenience sampling technique was used in recruiting eligible participants. Informed consent was taken through written consent before enrolment. An initial level of demographic data collection was done, and the pre-intervention VSWM was assessed.

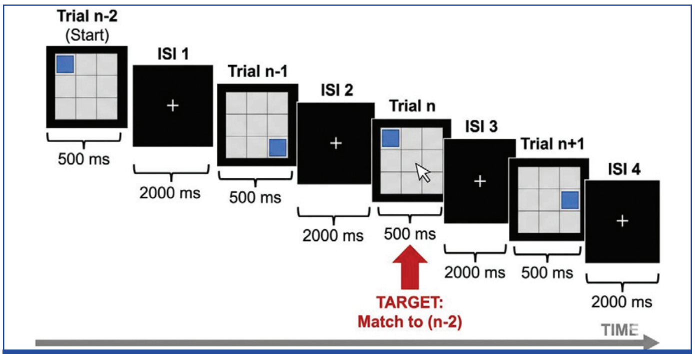
The VSWM was measured at two times, one at pre-intervention (baseline) and the other one at 72 hours post-intervention. Evaluations were performed by a trained evaluator, under standard procedures of administration.

Corsi Block-Tapping Task: The capacity of storing VSWM was measured using the Corsi Block-Tapping Task. It is made up of nine blocks placed spatially, which are tapped in soaring lengths by the assessor. The participants had to repeat the sequences. Forward conditions and backward conditions were given and composite span score was analysed. The maximum sequence that the participant reproduced correctly was the perception of the visuospatial memory range of the individual. The test has acceptable reliability among adults [21,22].

Visuospatial 2-back Task: The 2-back task of executing visuospatial was evaluated as a computerised one through E-Prime software. Pictorial elements were shown at various positions on a screen in sequence in different spaces. The stimuli were presented in 500 milliseconds surprising period and there was an Inter-Stimulus Interval (ISI) of 2000 milliseconds. Respondents answered in cases when the current stimulus was similar to the previous spatial position two trials before [Table/Fig-1]. On the 2-back task, sensitivity index (d′) and RT were noted as primary outcome. The 2-back test is a valid test of executive memory (working memory) and control of attention [23].

Pictorial elements were presented at various positions on the screen for 500 ms, followed by an Inter-Stimulus Interval (ISI) of 2000 ms. Participants responded only when the current stimulus position matched the position shown two trials prior (Trial N=Trial N-2).

Intervention Protocol: High Intensity Functional Training: The study involved a 6-week HIFT involving five closely monitored training sessions every week. The sessions took about 45 minutes each and were done under the supervision of the instructors.



[Table/Fig-1]: Schematic representation of the visuospatial 2-back task.

The sessions were started with a 10-minute dynamic warm up exercise and then a 20 minutes functional exercise circuit with resistance based and anaerobic exercises including squats, push-ups, presses, jumping exercises and short sprints. The exercises were done in turn after turn of work and rest of 30 seconds of activity and 30 seconds of rest respectively. After the two minutes rest, the circuit was re-done five times in total in each session. The end of each session was a five minutes cool-down with stretching exercises.

The intensity of the exercising was prescribed qualitatively as high intensity in line with the functional training protocols in previous studies [16]. No objective measures of exercise intensity through heart rate measurement or rating of perceived exertion was done. Any form of progression came by adding external resistance in a progressive manner and adding complexity of movement depending on the tolerance of the participants. The progression scheme was universalised, and the choice of load was personalised to make it safe.

The intervention period was followed-up by attendance. There were no incidents that were reported, and all enrolled participants had completed the intervention.

STATISTICAL ANALYSIS

The analysis of data was done with the Statistical Package of the Social Sciences version 26.0. The Shapiro-Wilk test was used to determine the data normality. The paired-sample t-tests were used to test normally distributed variables, and the Cohen d was used to compute the effect sizes. Wilcoxon signed-rank test and effect size were used to analyse non-normally data (ordinal data Corsi span scores) and the effect size is expressed as $r = |Z|/\sqrt{N}$. Independent-samples t-tests on normally distributed variables and Mann-Whitney U test on ordinal data were used to perform exploratory sex-based comparisons. Continuous variables are presented in the form of mean±standard deviation and ordinal variables in the form of median and interquartile range. The statistical significance was set at $p<0.05$.

RESULTS

The present study was completed by 72 participants who were used in the final analysis. There were no dropouts or data missing. All participants attended all the 6 weeks of the intervention.

[Table/Fig-2] represents the demographic features of the participants. The independent-samples comparisons of male and female subjects revealed that there is a significant difference in terms of height and weight ($p<0.001$) and no significant difference in terms of age or Body Mass Index (BMI).

Data on ethnicity, socioeconomic status, baseline physical fitness, occupational background, previous structured exercise history and use of medication was not gathered formally and thus could not be analysed.

Variable	Males (n=36)	Females (n=36)	p-value
Age (years)	42.1±4.6	41.7±4.9	0.72
Height (cm)	173.4±6.8	162.5±5.9	<0.001*
Weight (kg)	67.9±8.2	56.8±7.4	<0.001*
BMI (kg/m²)	22.6±2.7	21.5±2.9	0.09

[Table/Fig-2]: Demographic characteristics of the participants (n=72).
Values expressed as mean±SD. *Statistically significant at p<0.05. Independent t-test was applied
BMI: Body mass index

The composite Corsi Block-Tapping span score assessed changes in the VSWM storage capacity. [Table/Fig-3] shows median values of pre- and post-intervention. The median Corsi range improved between the baseline of 4.0 (IQR=1) and after the intervention (5.0, Interquartile Range (IQR)=2). This was found to be statistically significant (Z=5.108, p<0.001) and correlated with a big effect size (r=0.86).

Variables	Pre-intervention (Mean±SD)	Post-intervention (Mean±SD)	p-value	Effect size
2-back sensitivity (d′)	2.36±0.52	2.84±0.48	<0.001*	d=0.68
2-back Reaction Time (RT) (ms)	611±95	558±82	<0.001*	d=0.61
Corsi span†	4.0 (1)	5.0 (2)	<0.001*	r=0.86

[Table/Fig-3]: Visuospatial working memory performance pre- and post-HIFT (n=72).
Values are expressed as mean±standard deviation unless otherwise indicated.
†Reported as median (interquartile range). Paired t-test was used.
*Statistical significance set at p<0.05.

Considering that this was the second time that the Corsi task was performed, the noted increase is to be viewed with reservations, because the prevalence of practice effects might have led to the span performance modification.

The visuospatial 2-back was used to assess executive features of VSWM. After the intervention, there was a significant change in sensitivity index (d+) since it had increased to 2.84±-0.48 (t of 71=4.12, p<0.001; d=0.68). The mean RT with correct answers has reduced to 558±82 ms (t(71)=3.85, p<0.001; d=0.61) which means that there is a decrease in RT taken to execute the correct response [Table/Fig-3].

Though these results indicate better executive updating and processing speed, the lack of a non-exercise control group makes it difficult to separate the effects of the intervention on the executive updating and processing speed and the familiarity with the tasks.

Exploratory cross-gender comparisons of baseline male and female performance on VSWM showed no statistically significant differences in baseline performance or in change scores following intervention on the Corsi Block-Tapping composite score measurement or visuospatial 2-back task measure (all p>0.05). These results are shown in [Table/Fig-4].

Outcome measure	Time point	Males (n=36)	Females (n=36)	p-value
Corsi span†	Baseline	4.0 (1.0)	4.0 (1.0)	0.81
	Post-intervention	5.0 (1.0)	5.0 (1.0)	0.88
	Change (post–pre)	+1.0 (1.0)	+1.0 (1.0)	0.92
2-back sensitivity (d′)	Baseline	2.34±0.51	2.38±0.48	0.69
	Post-intervention	2.86±0.46	2.89±0.44	0.74
	Change (post–pre)	+0.52±0.30	+0.51±0.28	0.88
2-back Reaction Time (RT) (ms)	Baseline	618±94	604±88	0.47
	Post-intervention	561±81	555±79	0.66
	Change (post–pre)	−57±39	−49±41	0.44

[Table/Fig-4]: Gender-wise comparison of Visuospatial Working Memory (VSWM) outcomes (n=72).
• Values are expressed as mean±standard deviation unless otherwise indicated.
†Reported as median (interquartile range). Sex-wise comparisons were performed using independent samples t-tests for continuous variables and the Mann-Whitney U test for Corsi composite scores.
• Statistical significance was set at p<0.05.

DISCUSSION

The current pilot study investigated the relationship between the 6-week HIFT and the effects of the training on the alteration of VSWM in healthy adults of middle age. The results proved the statistically significant gains in the visuospatial storage capacity, gauged by the Corsi Block-Tapping Task, or in the speed of executive updating and processing, gauged by the visuospatial 2-back task. These findings indicate that the engagement in an organised high intensity functional exercise program could be linked to the immediate alteration of various elements of VSWM in the middle adulthood.

VSWM relies on the synchronised action in fronto-parietal neural networks that aid storage of information in space, control attention, and process information executively. Even in adult life, these networks are capable of plasticity that is dependent on experience. This research has demonstrated a relationship between exercise programs with complex motor coordination and high cognitive engagement and better performance in VSWM over less cognitively demanding tasks, which has been relative to older adults in previous studies involving children and adolescents [16,24-26].

The visuospatial 2-back task showed an improvement in the executive working memory performance, measured by the sensitivity (d’) and the shorter RT. The N-back task imposes demands of continuous updating, extended attention, and inhibitory control processes, which are mainly mediated by prefrontal cortical networks [27]. Improvement in executive domains with exercise has been proposed to be caused by an increase in cerebral perfusion, functional connectivity and up-regulation of neurotrophic factors including brain-derived neurotrophic factor [28,29]. Previous experimental studies have indicated that higher-intensity exercise modalities may produce more benefits in executive domains compared to lower-intensity exercise, especially when exercising is repeated over a period of weeks [16,25,30]. The present results are consistent with these findings, although causal conclusions cannot be drawn.

The measured span of Corsi Block-Tapping is to be taken with caution. Span-based visuospatial tests have been known to show a practice/familiarisation effect with repeated testing, with reported improvements of about 0.5 to 1.5 span units with no intervention [31,32]. It cannot be separated that intervention-related effects and test-retest learning effects because there was no non-exercise control group receiving the same cognitive testing. Based on this, the positive changes in this study are to be seen as correlational, but not conclusive, to show that training has led to the enhancement.

There were no significant differences in baseline VSWM or in response to the intervention in exploratory sex-based analyses. This observation is consistent with a previous study which has reported generally similar exercise-induced cognitive changes between the sexes among adult populations though sex differences might be contingent on training mode, level, and initial fitness [33]. These analyses were not powered to identify subtle sex-differences.

In general, the results of the present pilot study indicate the possibility of a high-frequency, high-intensity functional exercise program implementation in middle-aged adults and preliminary results about any measure in the visuospatial and executive working memory outcomes. Based on meta-analytic evidence, the exercise interventions with adequate intensity and duration have a higher probability of producing measurable cognitive benefits, especially to the executive functions [34,35]. But due to the methodological limitations of the current study, these results could only be regarded as hypothesis-generating and be used to design future randomised controlled trials.

Limitation(s)

The current study has a number of critical limitations. To begin with, the lack of an exercise-non exercise control group makes the results causal to interpret. The positive changes in cognitive performance could be partly attributed to the effects of practice related to repeated performing of the Corsi Block-Tapping and N-back tasks instead of the training intervention itself. Second, the convenience sampling and the single-arm design minimise the external validity of the findings. Third, objective measurement of exercise intensity was not done. The heart rate measurements, perceived exertion ratings and measures of physiological workload were not recorded and it could not accurately describe the intensity of the HIFT protocol or test dose response relationships between exercise intensity and cognitive outcomes. Fourth, a number of demographic and baseline variables that could affect cognitive responsiveness to exercise such as socioeconomic status, ethnicity, baseline physical fitness, previous exercise history, or medication use were not measured. Lastly, the somewhat brief intervention length and the lack of follow-up measures do not allow concluding on the long-term maintenance of the reported cognitive alterations.

CONCLUSION(S)

The present pilot study has shown that the statistically significant increase in VSWM storage and executive updating were related to the participation in a 6-week HIFT program among healthy middle-aged adults. There was an improvement in Corsi block-tapping span and visuospatial 2-back task performance. Such results indicate that HIFT in a structured and high-intensity format can be related to temporary improvements in visuospatial and executive cognition in middle adulthood. Nevertheless, the lack of a control group and the possible effects of the practise make the interpretation cautious. The findings can be viewed as preliminary and hypothesis-generating. These results will need future randomised controlled studies with objective intensity measures and extended follow-up to affirm these results and assess their clinical implications. High-intensity functional exercise could potentially be a viable and time-saving method related to enhancement of visuospatial and executive working memory in middle-aged adults, but confirmatory controlled research is needed.

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