

The Effects of Multi-Modal Intervention Protocols on Verbal Intelligence Domains in Pakistani School Students: A Randomized Crossover Trial

Muhammad Yasin Khan, Aisha Tauqeer & Muhammad Aqeel

Abstract

Background: The extent to which intellectual performance can be modulated remains a central debate in cognitive psychology. This study investigated the efficacy of longitudinal intervention protocols combining cognitive load (Dual n-back), physiological arousal (Aerobic Physical Exercise; APE), and sensory consolidation (Wakeful Rest) to determine the optimal sequence for enhancing verbal intelligence domains in adolescents.

Method: A 6-week, double-blind, randomized crossover trial was conducted with school-aged students ($N=25$, $M=12.98$). Using a within-subjects design, participants were exposed to six counterbalanced intervention sequences (e.g., N-R-E, E-N-R). Verbal Intelligence (VI) and its constituent indices the Working Memory Index (WMI) and Verbal Comprehension Index (VCI) were psychometrically evaluated weekly using the Wechsler Intelligence Scale for Children (WISC-IV).

Results: Repeated-measures ANOVA revealed significant main effects for both intervention condition and time across all measured domains ($F(1, 24) = 170.31$, $p < .001$). While isolated Dual n-back training showed strong independent effects, the data identified superior synergistic protocols. Post-hoc Bonferroni analysis confirmed that the N-R-E (Dual n-back -Wakeful Rest - Aerobic Exercise) and N-E-R (Dual n-back - Aerobic Exercise -Wakeful Rest) sequences yielded the highest significant improvements in verbal comprehension, digit span, and short-term memory ($p < .05$). The results demonstrated a significant ascent from a baseline mean of 94.85 ($SD = 25.48$) to a peak performance of 152.90 ($SD = 8.45$) by the final experimental trial. This substantial increase in primary scores was accompanied by a marked reduction in variance, suggesting that the N-R-E and N-E-R sequences effectively homogenized high-level cognitive performance across the cohort.

Conclusions: This study's findings suggest that verbal intelligence domains are highly plastic and responsive to specific behavioral sequencing. The results indicate that "cognitive priming" via n-back training, when followed by physiological stimulation or consolidation periods, maximizes neural receptivity and information retention. This provides a scalable framework for educational interventions aimed at optimizing cognitive development.

Keywords: Cognitive Training, Dual n-back, Aerobic Exercise, Wakeful Rest, Verbal Intelligence, WISC-IV, Neuroplasticity.

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Background

The debate regarding the malleability of intelligence the aggregate capacity to act purposefully, think rationally, and deal effectively with the environment remains a central focus of behavioral science (Clifford et al., 2011; Gkintoni et al., 2025; Lin et al., 2025; Momeni et al., 2026; Wahlsten, 1997). While traditional perspectives often viewed intelligence as a static trait, contemporary research increasingly explores the "nurture" aspect, investigating how physiological and environmental interventions can optimize cognitive architecture (Lei et al., 2025; Singh et al., 2025; Spitz, 2013). Verbal Intelligence (VI), comprising the Verbal Comprehension Index (VCI) and Working Memory Index (WMI) (D Wechsler, 1955), is particularly critical as it serves as a primary predictor of academic success and abstract reasoning (Ferrara et al., 1986).

Despite extensive research independently evaluating the cognitive benefits of wakeful rest and physical exercise, findings remain inconsistent due to variations in duration, intensity (Paillard et al., 2015), and behavioral metrics (Kramer & Colcombe, 2018). Furthermore, while the Dual n-back task has emerged as a potent tool for enhancing working memory, there is a significant scarcity of research providing a direct, simultaneous comparison of these three interventions within a single methodological framework (Gul et al., 2025; McCray, 2006; Stimpson et al., 2018).

This study addresses this gap by adopting a systematic approach to evaluate the synergistic effects of rest, aerobic exercise, and Dual n-back training on the verbal intelligence domains of school students in Pakistan (Gull et al., 2024, 2025; Jaeggi, Schmid, et al., 2008; Schweizer et al., 2013). By identifying the most effective sequencing of these interventions, this research aims to provide a scalable model for cognitive enhancement in educational settings, potentially resolving long-standing inconsistencies in longitudinal intellectual development.

Once observing the present study on above matter, the major focus was on the influenced of above three intervention programs on verbal intelligence, with well-built facts in support (Noor & Aqeel, 2025; Statton et al., 2015; Tariq et al., 2023). Many prior studies was conducted to examine the impact of exercise, dual n back and rest intervention on verbal intelligence, mixed findings have been reported. A study found that exercise had positive effect on cognition in over period of 3 months (Marin et al., 2018).

Conversely, Hötting and colleagues (2016) reported a continuous exercise condition has provided better performance as compare to temporary rest and exercise situations on a word recall training in young adults (Hötting et al., 2016). Continuous exercise refers as short, an aerobic, constant bursts of high-intensity exercise, usually from fifteen second to four minutes, separated by time of rest of a same period (Astorino & Schubert, 2018; Gull et al., 2024; Keating et al., 2017; Ramos et al., 2015).

It is also vital not to ignore the value of rest condition in cognitive studies, with facts recommending wakeful rest become useful for cognitive ability (Craig et al., 2016; Craig & Dewar, 2018). Dewar et al. (2012) clearly exposed that wakeful rest training with minimum sensory stimulation dragged to seventy three percent patients with amnesic were recalling greater than thirty percent of a writing style (Bibi & Aqeel, 2025). On the other hand, those patients who performing a cognitive task while wakeful rest (Abida et al., 2023; Dewar et al., 2012; Khan & Aqeel, 2022; Munawar et al., 2021; Naz et al., 2023; Tariq et al., 2023).

Several similar studies have revealed same findings of wakeful rest condition to enhance recall even once examined seven days later (Aqeel et al., 2024). It is recommended that a phase of cognitive impairment is an important for the consolidation of recently erudite stimuli or disturbance of this procedure can result novel memory traces to be ignored in favor of a new task (Abbasi & Aqeel, 2023; Dewar et al., 2012; Gul & Aqeel, 2021; Khan et al., 2022; Kuschpel et al., 2015; Yawar et al., 2022).

To investigate effectiveness of dual n back, wakeful rest and APE have been beneficial to verbal intelligence along its subsets as vocabulary, similarities, information, comprehension, arithmetic, digit span, letter- number sequencing abilities performance. For this purpose, this study focused on effect of three different types of interventions with unique combination to improve verbal intelligence. This study also compared combination of three interventions as R-N-E (rest-N back-Exercise), R-E-N (rest-exercise-n-back), E-N-R (Exercise-N-back-Rest), E-R-N (Exercise - Rest- N-back), N-R-E (N back- Rest-Exercise), and N-E-R (N back-Exercise-Rest) on working memory and verbal comprehension intelligence along its subscales over the period of 6 weeks to improve verbal intellectual ability in students sample.

Method

Research Design

This study employed a 6-week, double-blind, within-subjects randomized controlled trial (RCT) (Loprinzi, 2019; Wagner et al., 2019). A repeated-measures crossover design was utilized to evaluate the efficacy of different intervention protocols. Each participant completed six separate laboratory trials, with each session lasting approximately one to two hours. The study was conducted between March and April 2019 at The Yasin School System in Pakistan, an institution recognized by the Federal Board of Intermediate and Secondary Education (FBISE), Islamabad.

Participants

25 participants (12 males, 13 females) were recruited for the study. Participants ranged in age from 12 to 16 years, with a mean age of 12.98 years ($SD = 0.42$). The sample consisted of adolescents currently enrolled in the 6th through 8th grades. Inclusion criteria were broadly designed to ensure the sample reflected real-world adolescent characteristics. Enrollment in grades 6–8; aged 12–16 years; fluency in English; and adequate cognitive ability to complete the tasks.

Participants were excluded if they had a current diagnosis of any neurological or psychiatric disorder including Learning Disabilities, Attention Deficit Hyperactivity Disorder (ADHD), or substance-related disorders as determined by the Structured Clinical Interview for DSM-5 or ICD-10 standards. Furthermore, students with any physiological conditions that could interfere with the physical intervention protocols were excluded.

Participant Screening and Selection

Potential participants were recruited from a secondary school during regular hours. Following a broad study briefing, candidates underwent a formal medical evaluation to determine eligibility. Those meeting the inclusion criteria proceeded to a comprehensive psychological and neuropsychological baseline assessment (T_0). Medical examinations, lasting 45–60 minutes, were conducted by a certified medical officer to assess cardiovascular health (heart rate, blood pressure, pulmonary function), musculoskeletal integrity, neurological status, and personal/family medical history. Following the baseline screening, 25 participants were randomly assigned to a within-subject repeated measures protocol. Over a six-week period, all participants rotated through six intervention sequences: R-N-E, R-E-N, E-N-R, E-R-N, N-R-E, and N-E-R.

Randomization and Masking

Participants were randomly allocated to treatment sequences using a block randomization strategy (5 groups of 5 participants). Randomization was stratified by sex, age (12 and 16 years), and educational level to ensure balanced groups. To maintain experimental integrity, a double-blind protocol was implemented; participants, research assistants, and clinical assessors were masked to the specific intervention sequence allocations.

Intervention Protocols

The six-week program required participants to attend five sessions per week, totaling 10 hours and 30

minutes of intervention time. All sessions (Rest, Aerobic Exercise, and Dual n-back) were conducted on-site in dedicated school facilities (gymnasium, computer laboratory, and assembly hall). Adherence was strictly monitored; participants who failed to attend all sessions were excluded from the final analysis.

1. Aerobic Physical Exercise (APE)

Supervised by a certified kinesiologist, APE sessions consisted of a 5-minute warm-up, 20 minutes of cardiovascular training, and a 5-minute cool-down. Cardiovascular training was performed on a stationary ergometer (Stages Cycling, USA). Intensity was tailored to each participant's maximal aerobic capacity (determined by a pre-test VO₂ peak test). To ensure safety and protocol fidelity, a 5:1 participant-to-trainer ratio was maintained (Singh et al., 2025; Zheng et al., 2025).

2. Dual n-back Training (N)

Cognitive training utilized the Dual n-back task (Jaeggi et al., 2008), an adaptive performance task designed to enhance working memory. Participants monitored a sequence of visuo-spatial and auditory stimuli simultaneously on an iPad. The task required identifying when the current stimulus matched one presented n-steps prior. The difficulty level (n) was dynamically adjusted based on individual performance to maintain a high cognitive load.

3. Wakeful Rest (R)

The rest condition involved 30 minutes of passive wakeful rest (Lei et al., 2025; Veksler & Gunzelmann, 2018). Participants sat silently in a comfortable chair with eyes closed in a low-stimulus environment. To ensure consolidation and prevent mental rehearsal, researchers monitored participants to ensure they remained awake. Post-session interviews confirmed that participants did not engage in active stimulus rehearsal; those who reported doing so were excluded from the analysis.

Outcomes Measures

The primary outcome, verbal intelligence, was assessed using the Wechsler Intelligence Scale for Children (WISC-IV). A trained PhD scholar in psychology, supervised by a senior professional psychologist, administered the tests in a controlled, silent environment. The assessment focused on the Verbal Comprehension Index (VCI) and its sub-domains: Similarities, Vocabulary, Information, Comprehension, Arithmetic, and Digit Span. The WISC-IV demonstrated high internal consistency within this sample (Cronbach's $\alpha > .65$) across all trials. Higher scores indicated superior verbal intelligence and working memory efficiency (Wechsler, 1955; Wechsler & Kodama, 1949).

Procedures

Ethical Considerations

This study was sanctioned by the Institutional Ethics Review Committee of Foundation University Islamabad (Ref: HREC/08/Psy/167). The investigation was conducted in strict adherence to the ethical principles of the American Psychological Association (APA). Prior to enrollment, written and verbal informed consent was obtained from all participants and their legal guardians, emphasizing the voluntary nature of participation and the right to withdraw at any stage.

Experimental Design

This study employed a 6-week, double-blind, randomized crossover trial conducted in accordance with APA ethical standards and approved by the Institutional Ethics Review Committee of Foundation University Islamabad. To mitigate individual variability, 25 participants were counterbalanced across six intervention sequences (R-N-E, R-E-N, E-N-R, E-R-N, N-R-E, and N-E-R) involving wakeful rest (R), aerobic exercise (E), and Dual n-back training (N). Each weekly trial followed a rigorous test-intervention-test protocol: participants completed a baseline WISC-IV assessment (T₀), underwent a 30-minute standardized intervention, and were immediately re-evaluated (T₁, T₅) to capture the sequential impact on verbal intelligence.

The interventions were strictly controlled: Aerobic Physical Exercise (APE) involved 30 minutes of interval cycling on a stationary ergometer at 70–80% HR max; Wakeful Rest required sitting silently with eyes closed in a low-stimulus environment, with post-session screening to exclude those who engaged in mental rehearsal; and the Dual n-back task required simultaneous monitoring of visuo-spatial and auditory stimuli via iPad tablets. This repeated-measures design allowed for a precise analysis of how the temporal ordering of cognitive load, physical arousal, and physiological recovery optimizes intellectual performance.

Statistical Analysis

All statistical procedures were performed using IBM SPSS Statistics (v.23). Prior to the primary analysis, the data distribution was assessed for normality using skewness and kurtosis coefficients (Tabachnick & Fidell, 2017). To mitigate the impact of extreme outliers and potential ceiling effects, raw scores for all variables were transformed into standardized Z-scores, pooled across the five testing intervals (T₀ to T₄). Baseline group comparisons were conducted using two-way ANOVAs where applicable. In instances where the assumption of sphericity was violated, Welch's ANOVA was utilized to ensure robust group comparisons. To evaluate the longitudinal efficacy of the three interventions over the six-week trial period, Repeated Measures ANOVAs were employed. In this model, "Time" served as the within-subjects variable, while "Intervention Sequence" was treated as the between-subjects variable. Statistical significance for all tests was established at an alpha level of $p < .05$.

Results

Table 1 presents the descriptive statistics, including means (M), standard deviations (SD), and distribution characteristics (min, max, and kurtosis) for verbal intelligence and its associated sub-domains across six experimental trials. Baseline measurements (Trial 1) for the Verbal Comprehension Index (VCI) indicated a mean score of 94.85 (SD = 25.48). By the final trial (Trial 6), the mean VCI increased to 152.90 (SD = 8.45). Kurtosis values across all variables and trials remained within acceptable ranges, suggesting that the data met the assumptions of normality required for parametric analysis.

In Table 2, A two-way repeated-measures (factorial) ANOVA was conducted to evaluate the effect of intervention protocols (Independent Variable 1) and Time

(Independent Variable 2) on verbal intelligence and its sub-domains (Information, Vocabulary, Similarity, Comprehension, Arithmetic, and Digit Span). The analysis revealed a highly significant main effect for the intervention condition on overall Verbal Intelligence, $F(1, 24) = 170.31$, $p < .001$. This indicates that the specific sequencing of cognitive load (Dual n-back), physiological arousal (Aerobic Exercise), and consolidation (Wakeful Rest) significantly influenced cognitive performance.

Post-Hoc Comparisons of Intervention Sequences

A Bonferroni post-hoc analysis was performed to identify the most effective protocol. The results indicated a clear hierarchy of efficacy among the six experimental sequences: 1. The N-R-E sequence yielded the highest cognitive gains (M = 152.90, SD = 8.45), followed closely by the N-E-R sequence (M = 151.26, SD = 10.66). 2. The E-R-N (M = 147.03, SD = 11.54) and E-N-R (M = 136.23, SD = 18.11) protocols showed significant improvements over baseline but were statistically inferior to the "Cognitive-First" (N-back) sequences. 3. The R-N-E (M = 119.90, SD = 22.56) and R-E-N (M = 94.85, SD = 25.48) sequences resulted in the lowest comparative performance. These pairwise comparisons revealed that the mean differences between the high-performing "N-back First" sequences (N-R-E/N-E-R) and the "Rest First" sequences (R-N-E/R-E-N) were statistically significant ($p < .05$), suggesting that initiating the protocol with high cognitive load (priming) is essential for maximizing verbal intelligence outcomes.

The significant effects observed in the primary index were mirrored across all sub-scales. Specifically: the results Short-Term Memory (SM) demonstrated a significant improvement across trials, $F(1, 24) = 109.49$, $p < .001$, peaking at Trial 6 (M = 78.57). Further, the findings of Information (INFO) Showed robust gains, $F(1, 24) = 102.86$, $p < .001$, with the highest scores observed in the N-R-E condition. Moreover, the results of Logical Reasoning & Arithmetic revealed that Similarity (F = 212.14) and Arithmetic (F = 86.39) reached peak performance levels when cognitive training was followed by physical activity. Additionally, Attention & Concentration (Digit Span) demonstrated Significant differences were found between the baseline and the finalized intervention sequences, $F(1, 24) = 21.76$, $p < .001$.

Discussion

The primary objective of this investigation was to evaluate the comparative and synergistic efficacy of novel intervention protocols comprising wakeful rest (R), aerobic physical exercise (E), and Dual n-back cognitive training (N) on verbal intelligence and its constituent sub domains (Vocabulary, Similarities, Information, Comprehension, Arithmetic, and Digit Span) among school students. Our findings demonstrate that while all combinations exerted a positive influence on cognitive performance, a distinct hierarchical trend emerged. Specifically, sequences initiated with the Dual n-back intervention (N-E-R and N-R-E) yielded the most robust enhancements in verbal comprehension and working memory (WM) capacity compared to protocols led by rest or exercise.

Table 1

Mean, Standard Deviation and Kurtosis of Verbal Comprehension, Short Term Memory, Similarity, Information, Vocabulary, Arithmetic, Comprehension and Digit Span in School Students (N=25).

Trial 1						
Variables	K	Min	Max	M	SD	K
Short Term Memory	25	16.00	159.00	49.02	16.83	2.81
Verbal Comprehension Index	25	24.00	197.00	94.85	25.48	.16
Information	25	10.00	38.00	20.72	4.97	.32
Similarity	25	4.00	47.00	14.31	4.95	2.90
Arithmetic	25	6.00	146.00	36.81	16.93	2.76
Comprehension	25	0.00	38.00	23.01	6.88	-.71
Digit Span	25	6.00	23.00	12.21	3.58	.32
Vocabulary	25	6.00	146.00	36.81	16.93	2.76
Trial 2						
Short Term Memory	25	26.00	84.00	60.93	13.12	-.49
Verbal Comprehension Index	25	51.00	155.00	119.89	22.56	-.91
Information	25	11.00	38.00	24.77	4.88	-.40
Similarity	25	11.00	30.00	22.67	5.47	-.44
Arithmetic	25	14.00	64.00	45.68	12.11	-.69
Comprehension	25	10.00	34.00	26.77	4.98	-.99
Digit Span	25	7.00	23.00	15.25	3.81	.04
Vocabulary	25	14.00	64.00	45.68	12.11	-.69
Trial 3						
Short Term Memory	25	33.00	85.00	68.90	10.49	-1.14
Verbal Comprehension Index	25	76.00	16.00	136.23	18.11	-1.39
Information	25	18.00	38.00	26.43	2.93	-.26
Similarity	25	15.00	41.00	26.89	3.77	-.72
Arithmetic	25	22.00	70.00	53.57	10.25	-1.29
Comprehension	25	14.00	34.00	29.34	4.47	-1.42
Digit Span	25	8.00	24.00	15.33	4.37	.05
Vocabulary	25	22.00	70.00	53.57	10.25	-1.29
Trial 4						
Short Term Memory	25	48.00	91.00	74.80	7.59	-.787
Verbal Comprehension Index	25	11.00	159.00	147.03	11.54	-1.62
Information	25	17.00	30.00	28.43	2.19	-3.07
Similarity	25	10.00	31.00	28.08	4.25	-2.69
Arithmetic	25	32.00	64.00	58.51	6.60	-1.84
Comprehension	25	24.00	34.00	32.01	1.99	-1.09
Digit Span	25	7.00	27.00	16.29	4.29	.28
Vocabulary	25	32.00	64.00	58.51	6.60	-1.84

Trial 5						
Short Term Memory	25	44.00	86.00	76.97	6.75	-1.93
Verbal Comprehension Index	25	95.00	158.00	151.26	10.66	-2.56
Information	25	24.00	30.00	29.14	1.28	-1.77
Similarity	25	17.00	31.00	29.01	2.34	-3.12
Arithmetic	25	30.00	64.00	60.81	6.04	-2.60
Comprehension	25	21.00	34.00	32.30	2.58	-1.81
Digit Span	25	10.00	24.00	16.16	3.49	.06
Vocabulary	25	30.00	64.00	60.81	6.04	-2.60
Trial 6						
Short Term Memory	25	48.00	88.00	78.57	6.56	-2.48
Verbal Comprehension Index	25	116.00	158.00	152.90	8.45	-2.48
Information	25	21.00	30.00	29.46	1.25	-4.13
Similarity	25	16.00	31.00	29.47	1.78	-5.25
Arithmetic	25	32.00	64.00	61.08	6.13	-3.42
Comprehension	25	17.00	34.00	32.89	2.15	-4.47
Digit Span	25	10.00	24.00	17.49	3.28	-.14
Vocabulary	25	32.00	64.00	61.08	6.13	-3.42

Table 2

Mean differences between R-N-E (rest-N back-Exercise), R-E-N (rest-exercise-n-back), E-N-R (Exercise- N back-Rest), E-R-N (Exercise-Rest-N back), N-R-E (N back- Rest-Exercise) and N-E-R (N back-Exercise-Rest) experiment conditions on verbal intelligence along its domains in school students (N = 25).

Variables	R-E-N		R-N-E		E-N-R		E-R-N		N-E-R		N-R-E		F	p	i-j	Mean. D(i-j)	S.E	p	95% CI	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD							LL	UL
	94.85	25.48	119.9	22.56	136.23	18.11	147.03	11.54	151.26	10.66	152.90	8.45	170.31	.00						
VM															2>1	-25	2.45	.00	-32.27	-17.82
															3>1	-41.38 [†]	2.45	.00	-48.61	-34.15
															4>1	-52.18 [†]	2.45	.00	-59.41	-44.95
															5>1	-56.41 [†]	2.45	.00	-63.64	-49.18
															6>1	-58.05 [†]	2.45	.00	-65.28	-50.82
															3>2	-16.34 [†]	2.45	.00	-23.57	-9.11
															4>2	-27.14 [†]	2.45	.00	-34.37	-19.91
															5>2	-31.37 [†]	2.45	.00	-38.59	-24.14
															6>2	-33.01 [†]	2.45	.00	-40.24	-25.78
															4>3	-10.80 [†]	2.45	.00	-18.03	-3.57
															5>3	-15.03 [†]	2.45	.00	-22.26	-7.80
															6>3	-16.67 [†]	2.45	.00	-23.89	-9.44
SM	49.02	16.83	60.93	13.12	68.90	10.49	74.80	7.59	76.97	6.75	78.57	6.55	109.49	.00	2>1	-11.91 [†]	1.54	.00	-16.45	-7.37
															3>1	-19.88 [†]	1.54	.00	-24.42	-15.34
															4>1	-25.78 [†]	1.54	.00	-30.32	-21.24
															5>1	-27.95 [†]	1.54	.00	-32.49	-23.41
															6>1	-29.55 [†]	1.54	.00	-34.09	-25.01
															3>2	-7.97 [†]	1.54	.00	-12.51	-3.43
															4>2	-13.87 [†]	1.54	.00	-18.41	-9.33
															5>2	-16.04 [†]	1.54	.00	-20.58	-11.50
															6>2	-17.64 [†]	1.54	.00	-22.18	-13.10
															4>3	-5.90 [†]	1.54	.00	-10.44	-1.36
															5>3	-8.07 [†]	1.54	.00	-12.61	-3.53

															6>3	-9.67 [†]	1.54	.00	-14.21	-5.13
INFO	20.72	4.97	24.77	4.88	26.43	2.93	28.43	2.19	29.14	1.28	29.46	1.25	102.86	.00	2>1	-4.05 [†]	.47	.00	-5.42	-2.68
															3>1	-5.71 [†]	.47	.00	-7.08	-4.34
															4>1	-7.71 [†]	.47	.00	-9.08	-6.34
															5>1	-8.42 [†]	.47	.00	-9.79	-7.05
															6>1	-8.74 [†]	.47	.00	-10.11	-7.37
															3>2	-1.66 [†]	.47	.01	-3.03	-.290
															4>2	-3.66 [†]	.47	.00	-5.03	-2.29
															5>2	-4.37 [†]	.47	.00	-5.74	-2.99
															6>2	-4.69 [†]	.47	.00	-6.06	-3.32
															4>3	-2.00 [†]	.47	.00	-3.37	-.63
															5>3	-2.71 [†]	.47	.00	-4.08	-1.34
															6>3	-3.03 [†]	.47	.00	-4.40	-1.66
SM	14.31	4.95	22.67	5.47	26.89	3.77	28.08	4.25	29.01	2.34	29.47	1.79	212.14	.00	2>1	-8.36 [†]	.56	.00	-10.02	-6.69
															3>1	-12.58 [†]	.56	.00	-14.24	-10.91
															4>1	-13.77 [†]	.56	.00	-15.43	-12.11
															5>1	-14.70 [†]	.56	.00	-16.36	-13.04
															6>1	-15.16 [†]	.56	.00	-16.82	-13.49
															3>2	-4.22 [†]	.56	.00	-5.88	-2.56
															4>2	-5.41 [†]	.56	.00	-7.07	-3.75
															5>2	-6.34 [†]	.56	.00	-8.00	-4.68
															6>2	-6.80 [†]	.56	.00	-8.46	-5.14
															5>3	-2.12 [†]	.56	.00	-3.78	-.46
															6>3	-2.58 [†]	.56	.00	-4.24	-.92
AR	36.81	16.92	45.68	12.11	53.57	10.25	58.51	6.600	60.81	6.048	61.08	6.13	86.39	.000	2>1	-8.87 [†]	1.48	.00	-13.23	-4.52
															3>1	-16.76 [†]	1.48	.00	-21.12	-12.40
															4>1	-21.70 [†]	1.48	.00	-26.06	-17.34
															5>1	-24.00 [†]	1.48	.00	-28.36	-19.64
															6>1	-24.27 [†]	1.48	.00	-28.63	-19.91
															3>2	-7.89 [†]	1.48	.00	-12.25	-3.53

DIGIT	12.21	3.58	15.25	3.810	15.33	4.37	16.29	4.29	16.16	3.49	17.49	3.28	21.76	.000	-3.04	.54	.00	-4.63	-1.45	
															2>1					
															3>1	-3.12	.54	.00	-4.71	-1.53
															4>1	-4.08	.54	.00	-5.67	-2.49
															5>1	-3.95	.54	.00	-5.54	-2.36
															6>1	-5.28	.54	.00	-6.87	-3.69
															6>2	-2.24	.54	.00	-3.83	-.65
															6>3	-2.16	.540	.00	-3.75	-.57

Note. VM= Verbal intelligence; SM=Short term memory subscale of verbal intelligence; INFO =Information subscale of verbal intelligence; AR=Arithmetic of verbal intelligence; VOC=vocabulary of verbal intelligence; COMP=Comprehension of verbal intelligence; DIGIT=Digit Span of verbal intelligence, $p < .01$, $p < .00$, $p < .000$.

These results align with and extend existing literature regarding the plasticity of the Verbal Intelligence Index (VCI). Previous research has established that Dual n-back training significantly improves fluid intelligence and executive control (Craig et al., 2016; Craig & Dewar, 2018). Our data confirms this trend, suggesting that the Dual n-back acts as a "neural primer," increasing the signal-to-noise ratio within the prefrontal cortex. This "Cognitive-First" approach likely optimizes the brain's state for subsequent physiological arousal (exercise) or data consolidation (rest).

Furthermore, our study highlights the nuanced role of Aerobic Physical Exercise (APE). While exercise is traditionally linked to improved processing speed and executive function via molecular and cellular adaptations (Hötting et al., 2016; Stimpson et al., 2018), our findings suggest that its benefits are maximized when it follows high-load cognitive tasks. This suggests a "Bio-Algorithmic" synergy: the N-back task increases the demand for neural resources (Lussier et al., 2012), while subsequent aerobic exercise provides the physiological "boost" (increased BDNF and oxygenation) necessary to consolidate those gains (Owens et al., 2013).

Novel Contribution

The most significant contribution of this study is the identification of the optimal sequencing policy. Unlike previous research that examines these interventions in isolation, this study provides empirical evidence for the N-E-R (N-back-Exercise-Rest) and N-R-E sequences as superior models for cognitive enhancement. This suggests that the order of behavioral intervention is just as critical as the type of intervention, offering a new framework for "Active Learning" in educational and clinical settings.

Limitations and Future Directions

Despite the significant findings, certain limitations must be acknowledged. First, the sample size (N=25) and specific demographic focus (school students in Pakistan) may limit the generalizability of the results to broader populations or older age groups. Second, while the 6-week crossover design provides internal validity, the long-term retention of these cognitive gains beyond the intervention period remains to be explored.

Future research should utilize Neuroimaging (fMRI or EEG) to investigate the real-time neural connectivity changes associated with the N-E-R protocol. Additionally, applying this sequencing model to clinical

populations specifically those with ADHD or neurodevelopmental delays could provide a non-pharmacological pathway for managing cognitive deficiencies.

Conclusion

This study demonstrates that strategic combinations of cognitive training, physical activity, and wakeful rest can significantly optimize verbal intelligence in school students. The evidence identifies Dual n-back training as the most potent driver of cognitive improvement, particularly when integrated into the N-E-R sequence. These results indicate that cognitive overexertion is not a prerequisite for performance; rather, the precise temporal arrangement of mental load and physiological recovery dictates the magnitude of intellectual gain. These findings provide actionable guidelines for educators and clinicians. By adopting an "N-back First" approach, stakeholders can implement evidence-based protocols to enhance student performance in high-stakes environments, improve memory-dependent daily tasks, and provide targeted support for individuals with executive function deficits.

Ethical Consideration

The study was approved by Department of Psychology, Foundation University Islamabad (FUI). Consent Form was taken before taking data and participants were asked to take voluntary participation.

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Availability of data and materials

The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions/Author details

M. Aqeel conceptualized and designed the study, performed the formal statistical analysis, and was responsible for the original drafting and critical revision of the manuscript. M. Yasin Khan and A. Tauqeer coordinated participant recruitment and conducted the clinical evaluations. All authors have reviewed and approved the final version of the manuscript for publication.

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