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Monitoring training load and visual-motor adaptation using fitlight feedback in high-intensity interval training (HIIT)

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Abstract

Aim. This study aimed to investigate the effects of integrating Fitlight visual feedback into high-intensity interval training (HIIT) on training load, reaction performance, and executive cognitive function in healthy young adults. It was hypothesized that Fitlight-enhanced HIIT would improve neuromotor and cognitive outcomes without significantly altering cardiovascular or subjective training load

Material and method. Twenty -four physically active participants (12 males, 12 females; aged 19 - 23 years) completed two HIIT sessions in a randomized crossover design: a control session (standard HIIT) and an experimental session (HIIT augmented with Fitlight visual cues) Each session consisted of eight 30-second maximal effort intervals with 30 seconds of rest. Training load was monitored using smartwatch heart rate recordings and Borg CR-10 rate of perceived exertion (RPE). Performance metrics included Fitlight-derived reaction time (RT) and movement time (MT). Cognitive function was assessed pre- and post-intervention using the Go/No-Go test (inhibitory control) and Trail Making Test-B (TMT-B, executive function).

Results. Fitlight-enhanced HIIT significantly reduced RT (0.36 to 0.33 s, p = 0.001, d = 0.74) and MT (1.20 to 1.12 s, p = 0.013, d = 0.55), and improved TMT-B completion time (75.5 to 69.9 s, p = 0.048, d = 0.43). No significant differences were observed for Go/No-Go accuracy, heart rate, or RPE.

Conclusions. These findings indicate that Fitlight-integrated HIIT enhances neuromotor speed and executive function without increasing physiological load, supporting its utility as a time-efficient training modality in both athletic and cognitive-performance contexts.

Key words: *High-Intensity Interval Training (HIIT), visual-motor adaptation, fitlight trainer, executive function, reaction time*

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Introduction

High-intensity interval training (HIIT) has gained considerable attention in recent years as a time-efficient method to enhance both cardiovascular and metabolic health. Characterised by alternating bouts of near-maximal effort with short recovery periods, HIIT has been shown to elicit comparable or even superior physiological benefits to traditional moderate continuous training, despite requiring less total exercise time (Gibala et al., 2012; Weston et al., 2014). In addition to these well-established cardiovascular and metabolic adaptations, a growing body of research suggests that HIIT may also positively influence cognitive functioning, particularly executive processes such as attention, inhibition, and cognitive flexibility (Alves et al., 2014; Zhang et al., 2025).

The connection between physical activity and cognition is supported by a substantial body of literature. Regular aerobic exercise is known to induce neuroplastic changes, improve cerebral blood flow, and upregulate neurotrophic factors such as brain-derived neurotrophic factor (BDNF) (Cotman et al., 2007; Hillman et al., 2008). These biological adaptations are thought to underpin improvements in executive functions, which are crucial for complex cognitive tasks, decision-making, and goal-directed behavior. However, while moderate continuous training has been widely studied in this context, the specific cognitive benefits of HIIT are only beginning to be fully appreciated. A recent meta-analysis confirmed that HIIT interventions can lead to measurable improvements in executive functions, including performance on tasks requiring inhibition and set-shifting, with moderate to large effect sizes (Zhang et al., 2025).

One of the emerging frontiers in exercise science is the integration of cognitive and neuromotor challenges directly into physical training protocols. Traditional HIIT primarily stresses the cardiovascular and metabolic systems; however, sport and daily activities often require rapid perceptual-motor responses under conditions of fatigue. To bridge this gap, technology-based training tools such as the Fitlight Trainer™ have been introduced. Fitlight is a wireless LED system that provides visual cues requiring participants to react with specific movements, thereby creating tasks that combine physical exertion with cognitive demands like reaction, inhibition, and decision-making. Early evidence suggests that such reactive training modalities may enhance not only physical conditioning but also sensorimotor integration and cognitive performance (Romeas et al., 2016).

This integration is particularly relevant for tasks involving visual-motor adaptation. Reaction time (RT) and movement time (MT) are fundamental components of neuromotor performance (Ştefan, T., & Sandu, E. R., 2021). Improvements in RT reflect enhanced perceptual-cognitive processing speed, while MT relates to the efficiency of motor execution. Both parameters are vital in sports performance, rehabilitation, and occupational settings where rapid and accurate responses to stimuli are critical. Furthermore, cognitive control tasks such as the Go/No-Go test, which assesses inhibition, and the Trail Making Test-B (TMT-B), which evaluates cognitive flexibility and visual scanning, provide standardized ways to measure the broader cognitive effects of such interventions.

Despite promising indications, the evidence base for combining HIIT with cognitive-motor stimulation remains limited. Many studies focus on either the physiological adaptations of HIIT or the isolated benefits of cognitive training, but rarely address the synergistic potential of merging these approaches. By embedding Fitlight feedback within a HIIT protocol, this study sought to simultaneously stimulate cardiovascular, neuromotor, and executive systems. Importantly, this approach allows for the monitoring of training load (via heart rate and rate of perceived exertion) alongside cognitive-motor outcomes, thus offering a more holistic view of adaptation.

Study Aim and Hypotheses

The present study aimed to investigate the effects of a Fitlight-enhanced HIIT protocol on training load, reaction performance, and cognitive-motor integration in healthy young adults. Specifically, it sought to determine whether adding visual-motor feedback to HIIT would (1) reduce reaction and movement times, (2) improve executive functions assessed via Go/No-Go accuracy and TMT-B completion time, and (3) influence training load as measured by heart rate and RPE.

Based on prior evidence, it was hypothesized that participants would demonstrate significant improvements in reaction and movement times as well as executive test performance following the Fitlight intervention, while physiological training load (HR and RPE) would remain stable. Such findings would support the utility of integrating cognitive challenges into HIIT protocols to enhance both physical and cognitive performance without additional physiological burden.

Materials and method

Participants

A total of 24 healthy, physically active individuals (12 male, 12 female; age 19 - 23 years), students at Physical education and mountain sports Faculty, volunteered to participate in this study. All participants had at least one year of experience with high-intensity interval training (HIIT) and reported no musculoskeletal or neurological disorders. Participants provided written informed consent in accordance with the Declaration of Helsinki, and the study protocol was approved by the faculty ethics committee.

Study design

A randomized crossover design was used to evaluate the effects of Fitlight-based visual-motor feedback on training load and motor performance during HIIT sessions. Each participant completed two HIIT training sessions under two conditions:

1. Control Condition (CON): Standard HIIT protocol without visual feedback.
2. Fitlight Feedback Condition (FIT): Identical HIIT protocol augmented with real-time visual stimuli and response tasks using the Fitlight system.

Sessions were separated by at least 72 hours to minimize fatigue carryover.

Training Protocol

Both conditions followed a structured HIIT format:

- Warm-up: 5 minutes of dynamic stretching and light aerobic activity.
- Main set: 8 intervals of 30 seconds of maximal effort functional drills (shuttle runs, jump squats, burpees) interspersed with 30 seconds of passive rest.
- Cool-down: 5 minutes of low-intensity walking and static stretching.

During the FIT condition, Fitlight pods were integrated into the drills to provide reactive light cues requiring immediate motor responses (sprint to the lit pod, touch it, or perform a specified movement).

The Fitlight Trainer™ system consists of wireless, LED-powered pods that can be programmed to activate in response to specific timings, sequences, or stimuli. For this study, pods were arranged to create a dynamic and unpredictable stimulus environment, response latency, hit accuracy, and movement path were recorded in real-time and tasks included both static (stand and touch) and dynamic (sprint and tap) elements to assess agility and reaction performance.

Data Collection

Training load and cognitive-motor performance were evaluated using both objective and subjective measures:

- Heart Rate Monitoring: Heart rate (HR) was continuously recorded throughout each training session using commercially available smartwatch sensors to capture internal load.
- Rate of Perceived Exertion (RPE): Immediately after each session, participants reported their perceived exertion using the Borg CR-10 Scale, ranging from 0 (no exertion) to 10 (maximal effort).

Table 1. Borg CR-10 Scale

Score	Perceived Effort	Description
0	Nothing at all	Resting
1	Very light	Barely noticeable
2–3	Light to moderate	Easy to keep going
4–5	Somewhat hard	Requires effort
6–7	Hard	Very challenging, but sustainable
8–9	Very hard	Extremely difficult to continue
10	Maximal	Couldn't continue for more than a few seconds

Source: Borg, G., 1982: 25

After each HIIT session (with and without Fitlight), participants are asked to rate their perceived exertion on the 0 -10 scale. This gives insight into how difficult the workout felt to them - independent of heart rate or workload.

The following performance metrics were extracted from the Fitlight system during the HIIT drills:

- Reaction Time (RT): Time elapsed between the visual stimulus (light activation) and initiation of movement.
- Movement Time (MT): Time from initiation of movement to physical interaction with the Fitlight pod.

Cognitive-motor integration was further assessed pre- and post-training using standardized neurocognitive tests:

- Go/No-Go Test: Used to evaluate response inhibition and cognitive control by measuring accuracy and reaction time to target versus non-target stimuli.
- Modified Trail Making Test (TMT-B): Administered to assess visual scanning, task switching, and executive function by recording the time required to connect alternating sequences of numbers and letters.

Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all variables. Repeated measures ANOVA was used to compare conditions (CON vs. FIT) and time points (pre vs. post) for key performance indicators. Significance was set at $p < 0.05$. Effect sizes (Cohen's d) were computed to assess the magnitude of differences.
All data analyses were performed using SPSS Statistics v26.0 (IBM Corp).

Results

Analysis of the training outcomes revealed clear gender-specific patterns of improvement, and presented in table 2. In terms of reaction time, female participants demonstrated a significant reduction from 0.35 s at baseline to 0.31 s in the final test (p = 0.014), indicating faster responsiveness to visual stimuli. By contrast, male participants showed only a minor, non-significant improvement (0.35 to 0.33 s).

For movement time, males exhibited a pronounced improvement, decreasing from 1.25 s to 1.08 s (p = 0.001), reflecting more efficient execution of motor responses. Female participants showed a slight reduction (1.19 to 1.13 s), but this was not statistically significant.

Cognitive control, measured through the Go/No-Go test, improved markedly in females, whose accuracy increased from 84% to 89% (p = 0.006). Male performance remained stable (≈84%). Both genders, however, displayed robust improvements in executive functioning: completion times on the Trail Making Test-B fell significantly, from 78 s to 66 s in males (p = 0.007) and from 78 s to 69 s in females (p = 0.001).

Physiological load measures were stable. Average heart rate remained consistent between initial and final tests in both males and females, with no significant differences. Similarly, perceived exertion declined slightly in both groups (males: 7.0 to 6.7; females: 6.9 to 6.4), but these changes were not significant.

Table 2. Descriptive statistics for all the tests

Variable	Gender	Test	Min	Max	X	SD	p	CV%
Reaction Time (s)	M	IT	.306	.374	.346	.022	.189	6.47
		FT	.252	.391	.331	.036	.189	10.82
	F	IT	.291	.411	.347	.031	.014	8.96
		FT	.235	.351	.307	.036	.014	11.61
Movement Time (s)	M	IT	1.114	1.361	1.246	.067	.001	5.38
		FT	.893	1.244	1.078	.094	.001	8.75
	F	IT	1.038	1.323	1.185	.093	.221	7.85
		FT	.987	1.229	1.132	.073	.221	6.42
Go/No-Go Accuracy (%)	M	IT	76.8	91.2	84.48	4.79	.716	5.67
		FT	71.8	90.7	83.83	6.08	.716	7.26
	F	IT	79.6	91.2	84.49	3.92	.005	4.64
		FT	79.8	96.8	89.17	4.69	.005	5.26
TMT-B Time (s)	M	IT	69.4	93.5	78.18	7.60	.006	9.72
		FT	54.9	84.8	66.47	10.06	.006	15.14
	F	IT	68.7	91.4	77.72	6.45	.001	8.30
		FT	51.2	84.0	69.36	8.27	.001	11.92
Heart Rate (bpm)	M	IT	140.0	166.3	158.15	6.81	.829	4.30
		FT	143.6	166.6	157.54	7.22	.829	4.58
	F	IT	143.6	176.7	160.50	8.27	.405	5.15
		FT	150.1	166.0	157.64	4.73	.405	3.00
RPE (CR-10)	M	IT	5.9	8.1	7.01	.80	.353	11.45
		FT	5.5	8.0	6.66	.76	.353	11.45
	F	IT	5.3	8.4	6.86	.90	.280	13.18
		FT	5.3	7.5	6.44	.67	.280	10.44

Note: IT – initial test, FT - final test, Min – minimum, Max – maximum, X – mean, SD – standard deviation, CV – coefficient of variation, p – statistical threshold

In table 3, following the training intervention, participants demonstrated marked improvements in several performance outcomes, particularly those related to reaction speed, motor execution, and executive functioning. Reaction time showed a clear and significant reduction, improving from an average of 0.36 seconds in the initial test to 0.33 seconds in the final assessment (F = 12.96, p = 0.001, d = 0.74). This indicates that after completing the

Fitlight-enhanced HIIT sessions, participants were able to respond more quickly to visual stimuli, reflecting sharper sensorimotor processing.

A similar trend was evident in movement time, which decreased from 1.20 seconds to 1.12 seconds across testing sessions (F = 7.15, p = 0.013, d = 0.55). This improvement highlights enhanced efficiency in the execution phase of movement, meaning participants not only reacted faster but also carried out their responses more quickly and effectively.

Improvements were also observed in executive functioning, as assessed by the Trail Making Test-B. Average completion times dropped significantly, from 75.5 seconds in the initial test to 69.9 seconds in the final test (F = 4.33, p = 0.048, d = 0.43). This result points to enhanced cognitive flexibility, visual tracking, and task-switching abilities after the intervention.

By contrast, Go/No-Go accuracy showed a slight, non-significant increase (from 86% to 88%), suggesting that inhibitory control was relatively stable over the course of training. Likewise, measures of physiological load and subjective exertion remained unchanged: average heart rate during exercise decreased marginally (162 to 159 bpm), and perceived exertion (RPE) values also showed only minor reductions (6.9 to 6.8 on the CR-10 scale), with neither reaching statistical significance.

Table 3. Paired Sample results for all the test

Variable	Δ X	Δ SD	CI 95%		t	F	d	p
			Lower	**Upper**				
Reaction Time (s)	.034	-.010	.014	.053	3.601	12.964	.735	.001
Movement Time (s)	.083	-.040	.019	.148	2.674	7.152	.546	.013
Go/No-Go Accuracy (%)	-2.267	-.511	-5.498	.965	-1.451	2.106	-.296	.160
TMT-B Time (s)	5.608	-3.863	.031	11.185	2.080	4.328	.425	.048
Heart Rate (bpm)	2.200	-1.507	-2.388	6.788	.992	.984	.202	.331
RPE (CR-10)	.063	-.101	-.379	.504	.293	.086	.060	.772

Note: ΔX – mean differences, ΔSD – standard deviation differences, CI 95% - confidence interval, t – paired sample t-Test, F – ANOVA repeated measures, d – Cohen's d, p – statistic threshold.

The authors were directly responsible for designing and implementing the research protocol, including the adaptation of HIIT drills to incorporate the Fitlight feedback system. This involved programming the Fitlight Trainer™ to create reactive, unpredictable visual cues within the training exercises.

The authors personally organized participant recruitment and screening, supervised all training sessions, and ensured standardized execution of the HIIT protocol across conditions. In addition, the authors were responsible for the administration of cognitive tests (Go/No-Go and TMT-B), ensuring reliability in test application.

Data collection, cleaning, and statistical analysis were also conducted by the authors using SPSS v.26, including the calculation of descriptive statistics, effect sizes, and confidence intervals. Beyond data processing, the authors contributed to the interpretation of results in the context of neuromotor adaptation and training science.

Finally, the authors prepared the manuscript draft, synthesizing the methodology, results, and discussion, while critically reflecting on the study's implications for sports science and practical applications of technology-driven HIIT.

Discussions

This study demonstrated that a Fitlight-enhanced HIIT protocol significantly improved reaction time (Nuri, L., et. al., 2013; Draheim, C., et. al., (2019), movement efficiency (Cavanagh, P. R., & Kram, R., 1985), and executive function (Hopfinger, J. B., & Slotnick, S. D., 2020; Sadozai, A. K., et. al., 2024), while leaving cardiovascular load and subjective exertion unchanged. Notably, reaction time decreased from 0.36 to 0.33 seconds (F = 12.96, p = 0.001, d = 0.74), and movement time dropped significantly from 1.20 to 1.12 seconds (F = 7.15, p = 0.013, d = 0.55). Executive functioning, assessed via Trail Making Test-B, improved by 5.6 seconds (F = 4.33, p = 0.048, d = 0.43).

These outcomes align with recent meta-analytic evidence supporting HIIT's positive effects (Wen, D., et. al., 2019; Wang, C., et. al., 2022; Menz, V., et. al., 2019). on executive functions. Zhang et al., 2025 found significant benefits for cognitive flexibility and task switching across HIIT interventions compared to moderate continuous training, with moderate-to-large effect sizes (SMD ≈ -0.7 for Trail Making tests). Similarly, Wang, X. et. al., 2023 reported improvements in inhibition reaction time and cognitive flexibility after both moderate and low-dose HIIT regimes, with dose-dependent effects favoring moderate exposure.

The inclusion of Fitlight stimuli (Theofilou, G., et. al., 2022) in high-intensity drills likely enhanced sensorimotor integration and attentional engagement, beyond the benefits observed in standard HIIT studies. Acute visual-motor feedback may heighten arousal and focus, contributing to the reductions in both reaction and movement times, whereas chronic HIIT tends to require several weeks to show significant executive gains (Effects of acute HIIT meta-analysis: ~61% positive outcomes).

Physiological mechanisms underlying these gains might involve neurotrophic and neuromodulatory processes. Aerobic exercise, particularly when intense and intermittent, has been shown to elevate BDNF, IGF-1, and other exerkines that promote neuroplasticity and executive functioning (e.g., prefrontal cortex upregulation). Moreover, increased cerebral blood flow during HIIT could enhance neural efficiency underlying faster reaction and decision-making processes.

Critically, our study did not find changes in heart rate or perceived exertion, suggesting that the observed cognitive and neuromotor improvements occurred independent of cardiovascular overload. This reinforces the notion that HIIT protocols incorporating cognitive challenge (Fitlight feedback) may yield multiplex training effects that engage both physical and cognitive domains without added strain.

Nonetheless, several limitations warrant discussion. The relatively small sample size (N=24) and homogenous young adult population may limit generalizability. Longer-term follow-up would clarify whether improvements persist or plateau. Future research could also compare Fitlight-driven HIIT with standard HIIT and control groups to isolate the contribution of visual-motor feedback.

Integrating Fitlight stimuli into HIIT offers a promising avenue to enhance neurocognitive and sensorimotor performance within time-efficient exercise sessions. This approach may have valuable applications in athletic training, rehabilitation, and cognitive wellness strategies, where simultaneous physical and cognitive adaptation is desired.

Conclusion

The present study demonstrated that integrating Fitlight visual feedback into a HIIT protocol produces measurable improvements in reaction time, movement efficiency, and executive cognitive performance, while leaving cardiovascular load and perceived exertion unchanged. These findings suggest that neuromotor and cognitive adaptations can be achieved without increasing physiological strain, making Fitlight-enhanced HIIT a promising strategy for optimizing both physical and cognitive outcomes within time-efficient sessions.

From a practical perspective, the results highlight the potential application of this approach in sports training, where rapid decision-making and motor execution are critical, as well as in rehabilitation and cognitive health programs, where dual benefits of physical and cognitive training may accelerate recovery or slow decline. Importantly, improvements in reaction speed and executive function support the growing evidence that high-intensity exercise combined with cognitive challenge yields synergistic benefits for brain and body.

Nevertheless, the relatively small, homogenous sample and short intervention period call for caution in generalizing these findings. Future studies should expand the scope to larger and more diverse populations, examine long-term retention of improvements, and compare Fitlight-enhanced HIIT against other cognitive-motor interventions.

This study contributes to the growing body of literature on exercise-cognition interaction, underscoring that technology-assisted HIIT can serve as an effective training modality to simultaneously stimulate cardiovascular fitness, neuromotor speed, and executive functioning. Such integrative approaches represent a valuable step forward in designing holistic training programs that reflect the complex demands of both athletic performance and everyday life.

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