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Association of Martial Arts and Executive Functions in Children Aged 8–12 Years: A Cross-Sectional Study

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Abstract: Executive functions (EFs), including inhibitory control, working memory, and cognitive flexibility, are critical for cognitive development and academic success in children. Research suggests that structured physical activities, such as martial arts, are associated with better EFs, yet studies in non-Western contexts like Morocco are scarce. This study addressed this gap by examining the association between martial arts training and EFs among Moroccan children mean age = 10.20 years, SD = 1.30; 26 females and 34 males. A cross-sectional design was employed, comparing 30 children practicing full contact and kung fu in semi-urban clubs with 30 children engaging in unstructured play in rural areas. EFs were assessed using culturally adapted tests, including the Digit Span Test, Corsi Block-Tapping Test, Stroop Color-Word Test, and New Card Sorting Test, with composite scores for each EF domain. Non-parametric and parametric tests were used due to non-normal data distributions. Results indicated that the martial arts group outperformed the control group across all EF domains (inhibitory control: $d = -1.562$, $p < 0.001$; cognitive flexibility: $d = -0.826$, $p = 0.003$; Working memory: $r = 0.473$, $p < 0.001$), with inhibitory control as the strongest predictor of group membership ($b = -2.673$, $p = 0.003$, OR = 0.069). Cognitive flexibility mediated 41.7% of the association between martial arts and overall EF performance ($p = 0.010$). These findings suggest martial arts are associated with better cognitive development in Moroccan children, informing potential integration into educational curricula. The cross-sectional design and modest sample size limit causal inferences, warranting longitudinal research to explore working memory ability in diverse cultural settings.

Keywords: Martial arts, Executive functions, Moroccan children, Cross-sectional, Cognitive development

1. Introduction

Executive functions (EFs) encompass a set of higher-order cognitive processes that regulate goal-directed behavior by coordinating thoughts and actions (Collins & Koechlin, 2012; Diamond, 2013; Friedman & Miyake, 2017; Miyake *et al.,* 2000). These processes, comprising inhibitory control, working memory, and cognitive flexibility, are fundamental to academic achievement, problem-solving, and deliberate decision-making (Collins & Koechlin, 2012; Lehto *et al.,* 2003; Miyake *et al.,* 2000). Inhibitory control enables the suppression of irrelevant environmental stimuli, thereby reducing distractions and sustaining attentional focus (Friedman & Miyake, 2017; Verburgh *et al.,* 2014). Working memory supports the temporary storage and manipulation of verbal and visuospatial information, critical for effective task execution (Baddeley, 2012; Diamond, 2013; Hu *et al.,* 2025). Cognitive flexibility facilitates adaptive behavioral adjustments in response to changing task demands, interacting synergistically with other EF components (Diamond, 2013; Hu *et al.,* 2025). Collectively, these mechanisms underpin cognitive self-regulation, enabling individuals to navigate complex tasks and adapt to dynamic environmental demands.

A robust body of evidence highlights the role of physical activity, particularly structured sports, in enhancing EFs among children and adolescents (de

Greeff *et al.*, 2018; Feng *et al.*, 2023; Liu, 2022; Verburgh *et al.*, 2014; Xue *et al.*, 2019). Sports, defined as organized physical activities with specific movements, clear objectives, and formalized rules (Snyder *et al.*, 2015), extend beyond physical health benefits to foster psychological well-being, social integration, and musculoskeletal development, while also mitigating obesity risks and improving quality of life (Giordano *et al.*, 2021; Kadri *et al.*, 2019). The cognitive benefits of sports arise from two primary mechanisms: physiological, through enhanced neural activity, monoamine neurotransmission, neurotrophic signaling, and neuroplastic adaptations (Hillman *et al.*, 2008; Hötting & Röder, 2013; Zhang *et al.*, 2024); and cognitive-educational, wherein the acquisition of complex motor skills and movement coordination promotes decision-making and behavioral adaptability (Crova *et al.*, 2014; Diamond, 2015; Diamond & Lee, 2011; Fernandes *et al.*, 2022).

Martial arts, as a distinct category of sports, are particularly effective in enhancing EFs by integrating aerobic physical exertion with cognitively demanding strategic tasks (Contreras-Osorio *et al.*, 2022; Diamond & Lee, 2011). Disciplines such as judo, taekwondo, karate, and capoeira have been shown to improve inhibitory control, working memory, and cognitive flexibility in children aged 6–18 years (Fernandes *et al.*, 2022; Giordano *et al.*, 2021; Kadri *et al.*, 2019; Ng-Knight *et al.*, 2022). For instance, a randomized controlled trial demonstrated that taekwondo enhances self-regulatory capacity and attentional focus in children aged 7–11 years (Ng-Knight *et al.*, 2022). Meta-analytic evidence further suggests that open-skill activities, such as martial arts, are more effective than closed-skill exercises in improving working memory and cognitive flexibility (Feng *et al.*, 2023; Hu *et al.*, 2025; Qiu *et al.*, 2024). Neuroimaging studies indicate that martial arts augment activity in the dorsolateral prefrontal cortex, correlating with enhanced working memory and attention in children aged 8–10 years (Zhang *et al.*, 2024).

Despite the growing evidence base, the majority of studies on martial arts and EFs have been conducted in Western or Asian contexts, leaving a significant research gap in other cultural settings, such as Morocco (Hu *et al.*, 2025). Moroccan children aged 8–12 years are at a critical neurodevelopmental stage characterized by heightened neural plasticity, making this period optimal for EF development (Diamond, 2012, 2013). The limited research focusing on this demographic in Morocco underscores the need for culturally sensitive investigations that account for local educational systems and traditional physical activities (Zhang *et al.*, 2024). Such studies are essential to understanding how EFs can be supported in diverse socio-cultural contexts.

This cross-sectional study aims to address the research gap in understanding the association between martial arts and EFs among Moroccan children aged 8–12 years (Diamond, 2012; Hu *et al.*, 2025). By assessing inhibitory control, working memory, and cognitive flexibility, the study seeks to elucidate pathways for supporting cognitive development within the Moroccan context, with an emphasis on practical applications for educational and mental health interventions (Ng-Knight *et al.*, 2022; Fernandes *et al.*, 2022). Furthermore, it explores the potential integration of martial arts into Moroccan school curricula to enhance academic performance and psychological well-being, while accounting for cultural and social nuances (Hu *et al.*, 2025; Kern *et al.*, 2018).

2. Methodology

2.1 Design

This study employed a cross-sectional design to evaluate the association between martial arts (full contact and kung fu) and executive functions among Moroccan children aged 8–12 years (Grades 4–6) in a naturalistic setting. This design facilitated comparisons of performance between the martial arts and control groups at a single time point without experimental manipulation, enabling the examination of associations between martial arts participation and cognitive outcomes within a Moroccan cultural context. The approach aligns with prior research investigating the associations between physical activity and executive functions in culturally specific populations (Diamond & Lee, 2011; Giordano *et al.*, 2021; Hillman *et al.*, 2008; Hu *et al.*, 2025; Verburgh *et al.*, 2014).

2.2 Participants

The sample consisted of 60 Moroccan children with a mean age of 10.20 years (SD = 1.30); gender distribution: 26 females (43.3%) and 34 males (56.7%), evenly divided into two groups (n = 30 per group). Participants were recruited from a single geographical region in Morocco to minimize sociocultural variability, with consideration given to differences in access to sports infrastructure. The martial arts group comprised 30 children from a semi-urban area with access to organized full contact and kung fu clubs, selected

through convenience sampling from primary schools ; this group included 11 females (7 practicing full contact, 4 kung fu) and 19 males (13 practicing full contact, 6 kung fu). The control group included 30 children from a rural mountainous region lacking sports infrastructure, engaging in unstructured free play without participation in organized sports ; this group included 15 females and 15 males. Convenience sampling is consistent with prior studies on executive functions in context-specific settings (Giordano *et al.,* 2021; Verburgh *et al.,* 2014; Hu *et al.,* 2025). Children with cognitive or physical disabilities that could affect cognitive test performance were excluded, in accordance with standardized protocols (Kadri *et al.,* 2019; Ng-Knight *et al.,* 2022; Fernandes *et al.,* 2022).

2.3 Materials

Executive function performance was evaluated using a culturally adapted battery of neuropsychological tests developed (Er-Rafiqi, 2020; Er-Rafiqi *et al.,* 2022) administered in the participants' native language to ensure cultural relevance. The instruments included the Digit Span Test (Forward and Backward), which measured phonological loop capacity (Forward) and verbal working memory with updating (Backward) (Miyake *et al.,* 2000), where participants repeated digit sequences presented at one per second with progressively increasing length, scoring from 2 to 5 based on the longest correctly recalled sequence, with reliability reported by Er-Rafiqui (2022) as Cronbach's α = 0.85 and validity as r = 0.80 with standardized tests; the Corsi Block-Tapping Test (Forward and Backward), which assessed visuospatial sketchpad capacity (Forward) and visuospatial working memory (Backward) (Kessels *et al.,* 2000), where participants reproduced block-tapping sequences with scores ranging from 0 to 9 for the longest correct sequence, with reliability according to Er-Rafiqui (2022) as Cronbach's α = 0.82 and validity as r = 0.75; the Stroop Color-Word Test, which evaluated inhibitory control using a validated version (Golden & Freshwater, 2002), where participants named the ink color of conflicting words (e.g., "red" written in blue) with metrics including completion time (in seconds, using a stopwatch) and uncorrected errors, with reliability as per Er-Rafiqui (2020) as Cronbach's α = 0.89 and validity as r = 0.85; and the New Card Sorting Test (NCST, 48-card version), which measured cognitive flexibility (Heaton *et al.,* 1993), with metrics including (a) Number of Categories Completed (proficiency in rule-based categorization), (b) Perseverative Errors (persistence with incorrect rules), and (c) Non-Perseverative Errors (set-loss errors), with reliability as reported by Er-Rafiqui (2020) as Cronbach's α = 0.80 and validity as r = 0.78.

2.4 Procedures

Data collection occurred between October and November 2024 in controlled environments (quiet school classrooms) to minimize distractions and optimize cognitive performance, following standardized protocols (Diamond & Lee, 2011; Kadri *et al.,* 2019; Fernandes *et al.,* 2022). Trained researchers administered the tests uniformly in Moroccan Darija, with each participant completing the tests individually during morning sessions (15–20 minutes) to mitigate fatigue effects. A 5-minute practice session preceded the Stroop Test and NCST to familiarize participants with the tasks. Environmental conditions (lighting, noise, seating) were standardized across groups to ensure fairness. The martial arts group trained 3–4 sessions per week (90–120 minutes per session) for an average of 2.8 years (range 1–5 years) under qualified instructors in registered clubs; full contact sessions included warm-up, technical practice, sparring, and discipline-focused activities. Data were manually recorded and entered into an SPSS file (.sav) for analysis. Ethical approvals were obtained from the Educational Research Laboratory and local educational authorities, adhering to the Committee on Publication Ethics (COPE) guidelines (Ng-Knight *et al.,* 2022; Fernandes *et al.,* 2022). Written informed consent was secured from parents or guardians, and verbal assent was obtained from participants, who were informed of their right to withdraw without consequences (Hu *et al.,* 2025).

2.5 Ethical Considerations

Ethical approvals were granted by the Institutional Research Board and local educational authorities, ensuring compliance with standards for research involving minors (Kadri *et al.,* 2019; Ng-Knight *et al.,* 2022). Written parental consent and verbal child assent were obtained, with participants fully informed of their rights, including the option to withdraw without penalty. Data were handled confidentially, prioritizing participant welfare, in line with ethical guidelines in sport psychology research (Fernandes *et al.,* 2022; Hu *et al.,* 2025).

2.6 Statistical Analysis Procedures

All analyses were performed using R with compatible packages (e.g., psych, mediation, dplyr). The following steps were undertaken:

1 ***Descriptive Statistics:*** Calculated means, standard deviations, medians, and interquartile ranges (IQR) for individual variables (e.g., BDST, Duration, UE, PE) due to non-normal distributions, as confirmed by Shapiro-Wilk tests ($p < 0.05$ for most variables).

2 ***Normality Assessment:*** Applied Shapiro-Wilk tests to evaluate the normality of individual and composite variables, guiding the selection of appropriate statistical tests.

3 ***Variance Homogeneity:*** Conducted Levene's tests to assess variance homogeneity for composite scores (Working Memory, Inhibitory Control, Cognitive Flexibility), informing the choice of t-test variants.

4 ***Group Comparisons:*** Used Mann-Whitney U tests for non-normally distributed variables (Working Memory, BDST, Duration, UE, PE) and t-tests for composite scores (pooled for Inhibitory Control, unpooled for Cognitive Flexibility) with Bonferroni correction ($\alpha = 0.05/3 \approx 0.0167$) to control for multiple comparisons. Effect sizes (r for Mann-Whitney U, Cohen's d for t-tests) were reported.

5 ***Composite Score Creation:*** Standardized (z-scored) individual variables and averaged them using the dplyr package to create composite scores for Working Memory, Inhibitory Control, and Cognitive Flexibility.

6 ***Logistic Regression:*** Employed a Working ized linear model (glm) to predict group membership (Group_binary: martial arts vs. control) using composite scores, reporting odds ratios and Pseudo-R^2.

7 ***Principal Components Analysis (PCA):*** Performed PCA with varimax rotation using the psych package to extract three components (RC1, RC2, RC3), reducing dimensionality of the dataset.

8 ***Mediation Analysis:*** Conducted multiple mediation analysis using the mediation package with 5,000 bootstrap samples to examine RC1, RC2, and RC3 as mediators between group membership and Total EF score.

9 ***Outlier Detection:*** Identified outliers as values exceeding ±3 standard deviations and evaluated their impact on results.

10 ***Error Handling:*** Resolved technical issues, including package conflicts (e.g., MASS), errors in recode () functions, and effect size calculations, to ensure robust and reliable results.

Assumptions of normality and variance homogeneity were tested to select appropriate statistical methods. Technical challenges, such as package conflicts, were addressed to maintain analysis stability.

3. Results

This study investigated executive function differences between the Martial Arts (Group 1) and Control (Group 2) groups using data from nine variables: Forward Digit Span Test (FDST), Backward Digit Span Test (BDST), Forward Corsi Tapping Test (FCTT), Backward Corsi Tapping Test (BCTT), Task Duration (Duration), Uncorrect Errors (UE), Categories Completed (CC), Perseverative Errors (PE), and Non-Perseverative Errors (NPE). Composite scores for Working Memory, Inhibitory Control, and Cognitive Flexibility were derived, and principal components analysis (PCA) extracted three components (RC1, RC2, RC3). The analysis included descriptive statistics, normality and variance homogeneity tests, group comparisons, logistic regression, PCA, and multiple mediation analysis. Results are presented in three tables, with three illustrative figures referenced to enhance interpretation.

3.1 Descriptive Statistics

Descriptive statistics for the individual variables are presented in Table 1, including means, standard deviations, medians, and interquartile ranges (IQR) due to non-normal distributions for most variables (Shapiro-Wilk tests, $p < 0.05$ for Forward Digit Span Test, Backward Digit Span Test, Forward Corsi Block-Tapping Test, Backward Corsi Block-Tapping Test, Stroop Duration, Stroop Uncorrected Errors, Stroop Corrected Errors, and Stroop Possible Errors). The Martial Arts group showed higher median scores on Forward Digit Span Test, Backward Digit Span Test, Forward Corsi Block-Tapping Test, Backward Corsi Block-Tapping Test, and Stroop Corrected Congruency, and lower median scores on Stroop Duration, Stroop Uncorrected Errors, Stroop Corrected Errors, and Stroop Possible Errors. One outlier was identified in cognitive flexibility (New Card Sorting Test – number of perseverative errors) for the Control group (participant row 53, > ±3 SD).

3.2 Group Comparisons

Group differences on composite scores (Working Memory, Inhibitory Control, Cognitive Flexibility) were examined using Mann-Whitney U tests

for Working Memory (due to non-normality in the Control group, p = 0.010) and independent t-tests for Inhibitory Control (pooled variance, Levene's p = 0.262) and Cognitive Flexibility (unpooled variance, Levene's p = 0.009). Table 2 shows significant associations between group membership and all three composite scores (p < 0.0167, Bonferroni-corrected α = 0.05/3), with the largest effect size for Inhibitory Control (d = -1.562, p < 0.001), followed by Cognitive Flexibility (d = -0.826, p = 0.003) and Working Memory (r = 0.473, p < 0.001). Mann-Whitney U tests on individual variables showed significant differences for Backward Digit Span Test (p = 0.002, r = 0.404), Stroop Duration (p < 0.001, r = 0.455), Stroop Uncorrected Errors (p < 0.001, r = 0.542), and Stroop Possible Errors (p = 0.007, r = 0.350). Figure 1 (Panel A) presents boxplots of composite scores, highlighting the observed group differences and the outlier in Cognitive Flexibility (removal of which did not change statistical significance).

Table 1. Descriptive Statistics by Group

Variable	Group	Mean ± SD	Median (IQR)
Forward Digit Span Test (FDST)	Martial Arts	3.60 ± 0.67	3.50 (3.00–4.00)
	Control	3.37 ± 0.61	3.30 (3.00–3.75)
Backward Digit Span Test (BDST)	Martial Arts	2.70 ± 0.60	2.70 (2.30–3.00)
	Control	2.17 ± 0.59	2.10 (1.80–2.50)
Forward Corsi Tapping Test (FCTT)	Martial Arts	3.97 ± 0.67	4.00 (3.50–4.50)
	Control	3.67 ± 0.61	3.70 (3.20–4.00)
Backward Corsi Tapping Test (BCTT)	Martial Arts	3.43 ± 0.68	3.40 (3.00–4.00)
	Control	3.10 ± 0.71	3.10 (2.60–3.60)
Task Duration (Duration)	Martial Arts	207.47 ± 44.40	205.00 (180.00–230.00)
	Control	252.93 ± 40.41	250.00 (225.00–280.00)
Uncorrect Errors (UE)	Martial Arts	2.70 ± 1.56	2.50 (1.50–3.50)
	Control	4.67 ± 1.45	4.50 (3.50–5.50)
Categories Completed (CC)	Martial Arts	5.27 ± 0.64	5.30 (5.00–5.70)
	Control	4.63 ± 1.19	4.60 (4.00–5.50)
Perseverative Errors (PE)	Martial Arts	3.07 ± 2.10	3.00 (1.50–4.50)
	Control	5.87 ± 4.41	5.50 (3.00–8.00)
Non-Perseverative Errors (NPE)	Martial Arts	5.53 ± 2.32	5.50 (4.00–7.00)
	Control	7.37 ± 4.74	7.00 (4.50–9.50)

Note. M = Mean, SD = Standard Deviation, IQR = Interquartile Range. Martial Arts corresponds to Group 1 (n = 30), and Control corresponds to Group 2 (n = 30). Medians and IQR are reported due to non-normal distributions (Shapiro-Wilk, p < 0.05).

Table 2. Group Comparison Results for Composite Scores and Significant Individual Variables

Variable/Category	Test	Statistic	Degrees of Freedom	p-value	Effect Size	Significant (α = 0.0167)
Working Memory	Mann-Whitney U	697.000	NA	<0.001	0.473 (r)	Yes
Inhibitory Control	t-test	-6.048	58.000	<0.001	-1.562 (d)	Yes
Cognitive Flexibility		-3.199	39.990	0.003	-0.826 (d)	Yes
Backward Digit Span Test (BDST)	Mann-Whitney U	639.5	NA	0.002	0.404 (r)	Yes
Task Duration (Duration)		211.5	NA	<0.001	0.455 (r)	Yes
Uncorrect Errors (UE)		172.0	NA	<0.001	0.542 (r)	Yes

Perseverative Errors (PE)		267.5	NA	0.007	0.350 (r)	Yes

Note. Composite scores were calculated as the mean of standardized (z-score) variables: Working Memory (FDST, BDST, FCTT, BCTT), Inhibitory Control (Duration, UE), and Cognitive Flexibility (CC, PE, NPE). Effect size (r) for Mann-Whitney U tests calculated using the rstatix package; effect size (d) for t-tests is Cohen's d (pooled for Inhibitory Control, unpooled for Cognitive Flexibility). Bonferroni correction applied (α = 0.05/3 ≈ 0.0167). Negative t-statistics indicate lower means in the Martial Arts group.

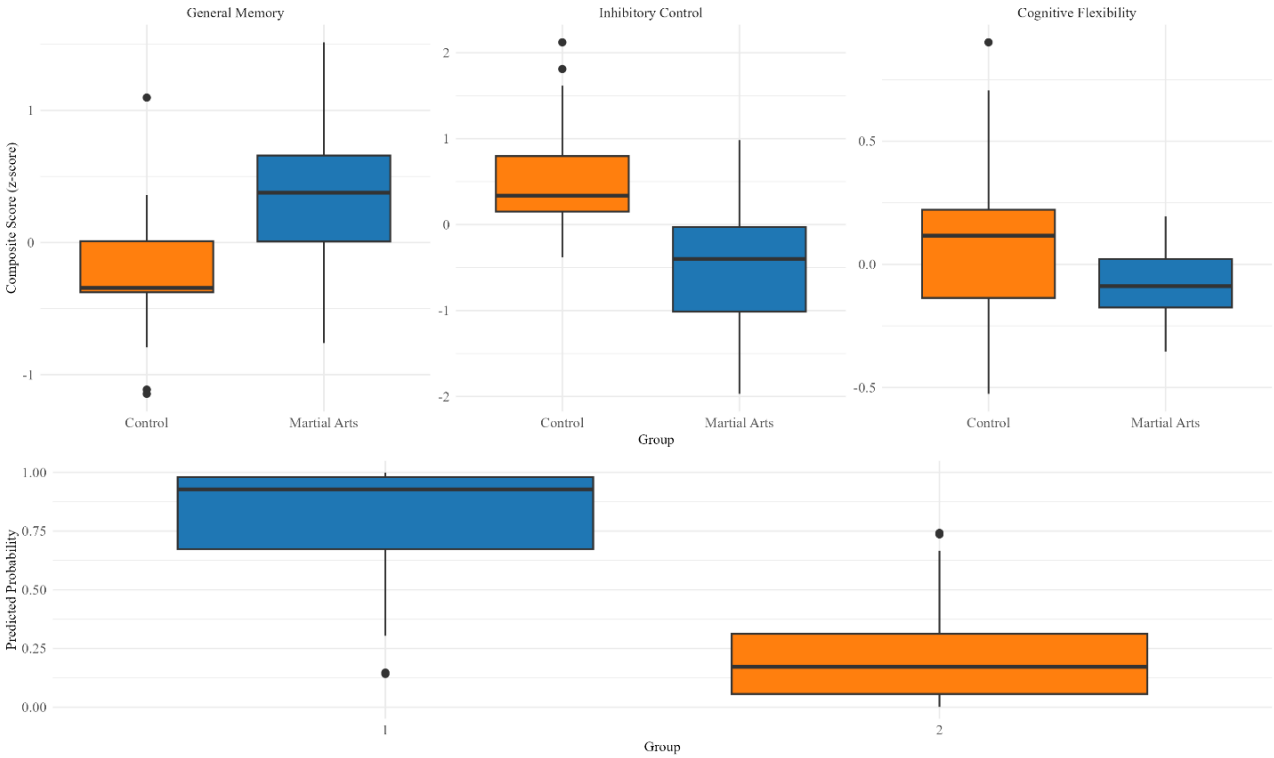

Figure 1. Composite Scores and Predicted Probabilities Panel A displays boxplots of composite scores (Working Memory, Inhibitory Control, Cognitive Flexibility) for the Martial Arts (blue) and Control (orange) groups, highlighting significant differences (Table 2) and an outlier in Cognitive Flexibility (row 53). Panel B shows boxplots of predicted probabilities from the logistic regression model (Table 3), illustrating moderate discriminative power (Pseudo-R^2 = 0.474).

Table 2 shows significant differences ($p < 0.0167$, Bonferroni-corrected $\alpha = 0.05/3$) for all composites, with the largest effect size for Inhibitory Control ($d = -1.562$, $p < 0.001$), followed by Cognitive Flexibility ($d = -0.826$, $p = 0.003$) and Working Memory ($r = 0.473$, $p < 0.001$). Mann-Whitney U tests on individual variables showed significant differences for BDST ($p = 0.002$, $r = 0.404$), Duration ($p < 0.001$, $r = 0.455$), UE ($p < 0.001$, $r = 0.542$), and PE ($p = 0.007$, $r = 0.350$). Figure 1 (Panel A) presents boxplots of composite scores, highlighting group differences and the outlier in Cognitive Flexibility.

3.3. Logistic Regression and Mediation Analysis

A logistic regression model predicted group membership (Group_binary: 1 = Martial Arts, 0 = Control) from composite scores. Table 3 shows that Inhibitory Control was a significant predictor ($b = -2.673$, $SE = 0.892$, $z = -2.995$, $p = 0.003$, $OR = 0.069$, 95% CI [0.012, 0.397]), indicating that higher Inhibitory Control composite scores were strongly associated with belonging to the Martial Arts group. Cognitive Flexibility was marginally significant ($b = -3.115$, $SE = 1.646$, $z = -1.893$, $p = 0.058$, $OR = 0.044$, 95% CI [0.002, 1.117]), and Working Memory was not significant ($p = 0.088$). The model explained 47.4% of the variance (Pseudo-R^2 = 0.474). Figure 1 (Panel B) shows boxplots of predicted probabilities, highlighting the observed association between higher executive function performance and martial arts group membership, with some overlap.

Aprincipal components analysis (PCA) with varimax rotation extracted three components: RC1 (Cognitive Flexibility, 30% variance), RC2 (Inhibitory Control/Spatial Memory, 23% variance), and RC3

(Working Memory, 13% variance), explaining 66% of the total variance (RMSR = 0.11, fit = 0.87, χ^2 = 50.54, p < 0.001). A multiple mediation analysis examined whether RC1, RC2, and RC3 mediate the association between Group and Total EF (sum of composite scores). Table 3 shows a significant total association (Estimate = -0.628, 95% CI [-1.068, -0.197], p = 0.003) and a significant indirect association through RC1 (Estimate = -0.262, 95% CI [-0.467, -0.070], p = 0.007), accounting for 41.7% of the total association between group and overall executive function performance (p = 0.010). The indirect association through RC3 was significant (Estimate = 0.133, 95% CI [0.003, 0.346], p = 0.043), and RC2 was marginally significant (Estimate = -0.202, 95% CI [-0.479, 0.013], p = 0.071). The direct association was not significant (p = 0.076). Figure 2 presents a bar chart of the mediation associations, highlighting the significant role of RC1, and Figure 3 displays a scatter plot of residuals versus fitted values from the mediation analysis.

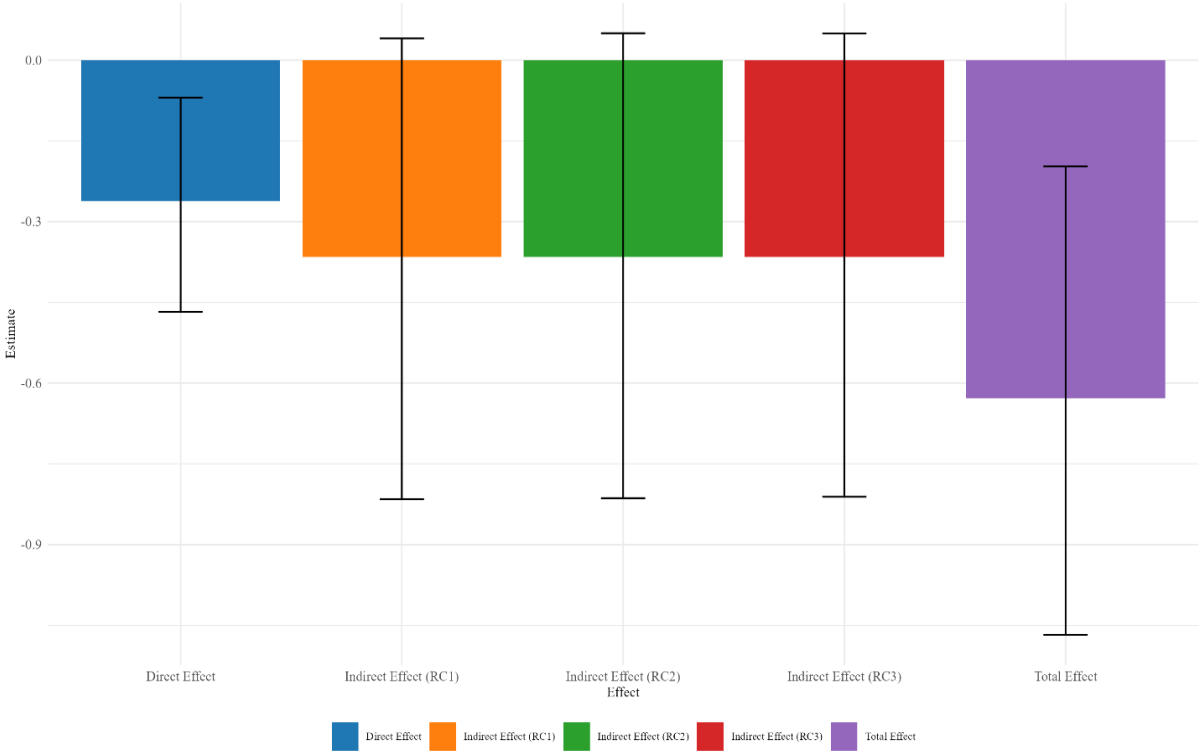

Figure 2. Mediation Paths for Multiple Mediators, This figure presents a bar chart of direct, indirect (RC1, RC2, RC3), and total effects from the multiple mediation analysis (Table 3), using blue, orange, green, red, and purple, highlighting the significant mediation through RC1 (41.7% mediated).

Table 3. Logistic Regression and Multiple Mediation Analysis Results

Analysis	Predictor/Effect	Estimate	SE	z/t	p-value	Odds Ratio	95% CI Lower	95% CI Upper
Logistic Regression	(Intercept)	0.129	0.403	0.320	0.749	1.138	0.516	2.509
Logistic Regression	Working Memory	1.298	0.762	1.704	0.088	3.661	0.823	16.285
Logistic Regression	Inhibitory Control	-2.673	0.892	-2.995	0.003	0.069	0.012	0.397
Logistic Regression	Cognitive Flexibility	-3.115	1.646	-1.893	0.058	0.044	0.002	1.117
Mediation Analysis	Direct Effect	-0.366	-	-	0.076	-	-0.816	0.040
Mediation Analysis	Indirect Effect (RC1)	-0.262	-	-	0.007	-	-0.467	-0.070

Mediation Analysis	Indirect Effect (RC2)	-0.202	-	-	0.071	-	-0.479	0.013
Mediation Analysis	Indirect Effect (RC3)	0.133	-	-	0.043	-	0.003	0.346
Mediation Analysis	Total Effect	-0.628	-	-	0.003	-	-1.068	-0.197

Note. Logistic regression predicts Group_binary (1 = Martial Arts, 0 = Control) from composite scores (Pseudo-R^2 = 0.474). Mediation analysis estimates are based on 5,000 bootstrap samples using the percentile method. RC1 = Cognitive Flexibility, RC2 = Inhibitory Control/Spatial Memory, RC3 = Working Memory. Effects are significant if $p < 0.05$ and 95% CI does not include zero. RC1 mediates 41.7% of the total effect ($p = 0.010$).

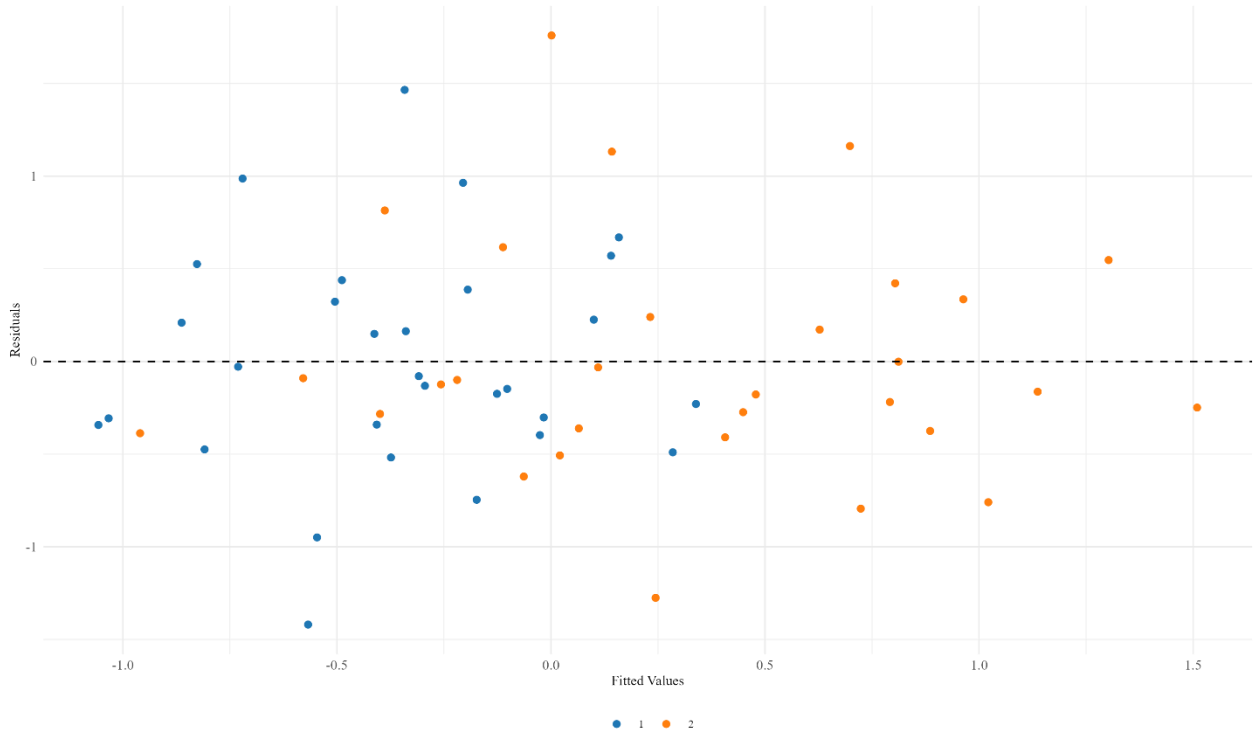

Figure 3. Mediation Residuals this figure displays a scatter plot of residuals versus fitted values from the mediation analysis, with points colored blue for Martial Arts and orange for Control.

The direct effect was not significant ($p = 0.076$). Figure 2 presents a bar chart of the mediation effects, highlighting the significant role of RC1 and figure 3 displays a scatter plot of residuals versus fitted values from the mediation analysis.

4. Discussion

This study explored the association between martial arts training and EFs, including Working memory, inhibitory control, and cognitive flexibility, among Moroccan children aged 8–12 years. The findings revealed that children participating in martial arts showed better performance than those in the control group across all three EF domains, with the strongest association observed for inhibitory control, followed by cognitive flexibility and Working memory. These results align with prior research indicating that martial arts, which combine physical activity with cognitive demands, are associated with enare associated with better executive functions in children (Diamond, 2013; Ng-Knight *et al.,* 2022; Contreras-Osorio *et al.,* 2022). Notably, group differences in tasks such as the Backward Digit Span Test, Task Duration, Incorrect Errors, and Perseverative Errors suggest that martial arts are particularly associated with stronger working memory and inhibitory control, consistent with studies on open-skill exercises (Feng *et al.,* 2023; Hu *et al.,* 2025; Kadri *et al.,* 2019; Fernandes *et al.,* 2022).

Inhibitory control emerged as the strongest predictor of whether children belonged to the martial arts group, reflecting a robust association with self-regulatory capacities. This association may be related to

the discipline, focus, and strategic decision-making inherent in martial arts training, as supported by studies on specific disciplines like Taekwondo and Capoeira (Ng-Knight *et al.,* 2022; Kadri *et al.,* 2019; Fernandes *et al.,* 2022). Cognitive flexibility showed a weaker association, while Working memory was not a significant predictor, suggesting that martial arts participation is more strongly associated with self-regulation rather than with memory processes. Mediation analyses indicated that cognitive flexibility and Working memory contribute to the observed association between martial arts participation and overall EF performance, possibly related to the need to adapt strategies in dynamic training scenarios (Diamond, 2013; Fernandes *et al.,* 2022; Roebers *et al.,* 2014). These associations are further supported by neuroscientific evidence linking physical activity to increased dorsolateral prefrontal cortex activity, which underpins multiple cognitive domains (Hu *et al.,* 2025; Zhang *et al.,* 2024b).

This study extends the evidence for associations between martial arts participation and cognitive outcomes to a non-Western context, addressing a critical gap in the literature, which has predominantly focused on Western or Asian settings (Biedrzycki & Laskowski, 2024; Hu *et al.,* 2025). The stronger association with inhibitory control compared to cognitive flexibility is consistent with specific demands of the martial arts training protocol, which appears to prioritize sustained attention and error suppression over rapid task-switching (Feng *et al.,* 2023; Lakes & Hoyt, 2004). Additional qualitative evidence, as noted by Pujari (2024), indicates that martial arts practice is associated with cognitive gains through structured routines and mentor-guided interactions (Pujari, 2024), aligning with Moroccan cultural values of discipline and community. In parallel, Kadri *et al.* (2019) emphasize that Taekwondo is associated with improved selective attention in adolescents, thereby supporting the observed associations between such practices and inhibitory control in the present study.

A major strength of this study lies in its methodological rigor, demonstrated by the utilization of validated composite scores derived from standardized instruments and the application of suitable statistical methods for non-normal data (Ng-Knight *et al.,* 2022; Fernandes *et al.,* 2022).

Nevertheless, the cross-sectional design does not allow causal interpretations, as pre-existing variations in executive functions or unmeasured confounding variables, such as socioeconomic status or parental involvement, cannot be excluded. Additionally, the relatively small sample size and focus on a single geographic region may limit the generalizability of the findings, particularly within the Moroccan context, where cultural and educational factors, such as collectivist values and restricted access to sports facilities in rural areas may be associated with executive function development (Diamond, 2013; Hu *et al.,* 2025). Furthermore, the initial limited description of the martial arts training protocol restricted the ability to identify which specific components are most strongly associated with the observed differences in executive functions.

These findings suggest that culturally adapted martial arts programs may be associated with positive cognitive development in Moroccan children, consistent with traditional values of discipline and community. However, barriers such as resource constraints and gender norms in sports participation, particularly in rural areas, require further exploration. Future longitudinal studies or randomized controlled trials in the Moroccan context are needed to establish the directionality of the observed associations and to evaluate whether martial arts interventions tailored to local cultural norms. Such research could inform educational policies, potentially integrating martial arts into school as a strategy associated with improved executive functions while addressing Morocco's unique sociocultural dynamics (Biedrzycki & Laskowski, 2024; Roebers *et al.,* 2014).

5. Conclusion

In summary, this cross-sectional study revealed significant positive associations between martial arts participation and executive functions; particularly inhibitory control; in Moroccan children aged 8–12 years. These findings suggest potential value for culturally adapted martial arts programs in supporting cognitive development within non-Western educational contexts. Due to the cross-sectional design, causal inferences are not possible; longitudinal and experimental studies are required to further examine these associations.

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Author Contribution Statement

Hamid Kaddouri- Conceptualization, Methodlogy, Investigation, Formal analaysis, Writing original manuscript. Salahddine Zerouali- Investigation, Formal analaysis, Writing original manuscript. Abdelouahed El-kamia- Methodlogy, Formal analaysis, Writing Review and Editing. Abdelaziz ElAlaoui ElAmrani - Formal analaysis, Writing Review and Editing. All the authors read and approved the final version of the manuscript.

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Ethics approval for this study was obtained from IRB.

Informed Consent

Written parental consent and verbal child assent were obtained, with participants fully informed of their rights, including the option to withdraw without penalty.

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Yes