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# Effects of Capoeira on children's executive functions: A randomized controlled trial

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ABSTRACT

*Purpose:* A growing body of evidence suggests that the benefits of exercise go far beyond physical health and may include cognitive gains. Capoeira is an Afro-Brazilian martial art that challenges Executive Functions (EFs), and inspires children's commitment in an environment characterized by positive affect, inclusiveness, and camaraderie. The primary aim of the study was to evaluate the effect of Capoeira on EFs in children. The secondary aims were to look at the effects of Capoeira on academic achievement and motor function and to look at dose-response effects of Capoeira on EF.

*Methods:* In this randomized controlled trial, 67 children (aged 8–13 years) were randomly assigned to Capoeira instruction (n = 37) or a wait-list control group (n = 30). Children in the Capoeira group participated in 60-min Capoeira classes three times per week. The Stroop Test, EF subtests of the Wechsler Intelligence Scale for Children, an Academic Achievement Test, agility and eye-hand coordination tests were conducted before and after the intervention period.

*Results:* ANCOVA analyses, controlling for sex and age, revealed that children who attended at least 70% of the Capoeira classes improved more in eye-hand coordination than the control group. There was also a positive association between EF improvement and the number of Capoeira classes attended.

*Conclusion:* The results suggest that Capoeira practice benefits eye-hand motor coordination in children and that the improvements in EFs might be dose-dependent. The results highlight the need for further studies to determine the potential advantages of adopting Capoeira as a holistic movement practice for children.

## 1. Introduction

Throughout most of human evolution, our ancestors walked many miles daily and were physically very active (Pontzer, 2017). We are biologically designed to move. Following this natural pathway of development leads most children to acquire fundamental movement skills around the age of 6 (Gallahue, Ozmun, & Goodway, 2013). Perhaps, it is no coincidence that children begin to acquire literacy skills around the same time (Seymour, Aro, & Erskine, 2003). Thus, if an environment for children's play is provided, enriched with physical activities, full of affective and cultural meaning, which requires children's social skills, decision-making and, response inhibition, children will tend to be emotionally and cognitively motivated to participate (Pesce et al., 2021).

Children who are more physically active tend to perform better in school (Singh, Uijtdewilligen, Twisk, Mechelen, & Chinapaw, 2012). Studies have consistently shown that people who are more physically active and have better aerobic fitness have better executive functions (EFs) than those who are more sedentary, a phenomenon that applies to both children (Scudder et al., 2014) and adults (Boucard et al., 2012).

EFs are a set of cognitive abilities that include working memory, inhibitory control (self-control and attention regulation), and cognitive flexibility (Diamond, 2013; Miyake et al., 2000). EFs are crucial for success in many aspects of life (Diamond, 2013) including schooling

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(Watts, Gandhi, Ibrahim, Masucci, & Raver, 2018). Individuals with better EFs tend to have a better quality of life, more academic, social and professional success, and better mental and physical health (Moffitt et al., 2011).

Despite evidence that people with better aerobic capacity tend to have better EFs and academic performance, interventions focusing on improving aerobic capacity have repeatedly shown disappointing results in improving EFs or academic performance (Diamond & Ling, 2019a; Singh et al., 2019). It has been hypothesized that physical activities that place a higher demand on motor and cognitive skills are more successful at improving cognition (Best, 2010; Diamond, 2015). Thus, there is great interest in research focusing on interventions using open-skill tasks (performed in unpredictable and changing environments), and martial arts that involve significant motor complexity (Lakes & Hoyt, 2004; Moreau, Morrison, & Conway, 2015; Pesce, Croce, et al., 2016).

The improvement in EFs promoted by aerobic exercise interventions with greater motor and cognitive engagement has been only slightly better than that achieved by focusing on aerobic capacity alone (Diamond & Ling, 2019b). Studies that have directly compared EF benefits from more versus less cognitively-demanding aerobic exercise showed that aerobic exercise with added cognitive and motor skill demands tends to improve EFs more than aerobic exercise that is less demanding in this regard (Moreau et al., 2015; Schmidt, Jäger, Egger, Roebers, & Conzelmann, 2015). Studies of open-skill sports and martial arts are also showing promising results in terms of the benefits to EFs (Alesi, Bianco, Luppina, Palma, & Pepi, 2016; Lakes & Hoyt, 2004).

Diamond and Ling (2019a, 2019b) have argued that the effects of cognitive and motor skill components of an activity on EFs are dependent on whether they form an intrinsic part of the activity, or are added artificially as isolated components of a sport performed out of context (i.e. not as part of a sport). The researchers hypothesized that practicing decontextualized skills has less benefit than practicing those skills as part of an activity or sport to which the participants are committed (Diamond & Ling, 2019b).

When performed as collective and cooperative activities, team sports and martial arts promote commitment and a sense of camaraderie, which may be critical aspects of the mechanism underlying the improvement in EFs. Diamond (Diamond, 2012; Diamond & Lee, 2011; Diamond & Ling, 2016, 2019b) proposed a mechanism to explain why programs seeking to improve EFs and/or academic achievement cannot ignore emotional and social needs if they hope to see extensive benefits.

Capoeira is an Afro-Brazilian martial art that involves music, dance, fighting and play in a multisensory, cooperative, and ritualistic environment that echoes back to its ancient origins in African cultures. Developed by enslaved Africans in Brazil, this art form seems to emerge to attend to their needs for social and corporal freedom, necessities that still remain in contemporary society. Capoeira has been crucial for safeguarding Afro-Brazilian culture, creating space for the propagation of related cultures such as afro-descendant religions and the ritualistic dances of Jongo and Maculelê (Almeida, 1993; Assunção, 2005). Thus, Capoeira has become a mainstay of the Brazilian cultural heritage, incorporating cultural, historical, and philosophical aspects of the African legacy in Brazil.

Capoeira is a highly complex practice that involves a two-person dance-combat-game executed under musical stimulation. It heavily engages working memory, inhibitory control, and cognitive flexibility as each practitioner properly responds to and executes blows, feints and acrobatic maneuvers, all improvised, and interwoven in a multi-segmental, multi-planar, slow and fast, stable and unstable, multi-task practice that also involves highly aerobic efforts (Lewis, 1994; Moreira, Teixeira-Araujo, Oliveira Dos Santos, & Simões, 2016). This embodied art form addresses socio-emotional skills within an enriched environment that cultivates the eudaimonic sense of well-being and spirituality as well as the hedonic sense of pleasure and joy, while also challenging EFs and motor coordination in several ways. In this sense, Capoeira can be characterized as a "holistic movement practice", an emergent term that refers to a plethora of aspects of physical exercise that transcend the common focus on energy expenditure (Vergeer & Biddle, 2021). The unpredictability of the Capoeira game enhances cognitive engagement and provides excellent EF training (Moreau & Conway, 2013, 2014), requiring practitioners to change their behavior constantly according to the game's situation. The Capoeira game also demands processing highly variable visual and auditory stimuli, since rhythm, melody and the song's lyrics influence the players' actions.

The Capoeira game happens within the ritual of the Capoeira circle and it is based on the connection promoted by the music, followed by participants singing and clapping. Thus, cooperation permeates all activities in Capoeira, promoting a sense of camaraderie, mutual support, and increasing self-esteem and self-confidence (Silva & Heine, 2008).

The primary aim of this study was to evaluate the effect of 4 months of Capoeira classes on children's EFs. As a secondary aim, we assessed the effects of this program on academic achievement and motor function and the dose-dependent effect on EFs. Given that the practice of Capoeira challenges EFs, improves cardiovascular fitness and motor coordination, creates a sense of group belonging and cooperation, and generates feelings of joy, pride, and self-confidence, we predicted that attending Capoeira classes on a regular basis (>70% of classes) would significantly improve EFs, while attending Capoeira classes occasionally (<70% of classes) would not significantly improve EFs. We also expected an improvement in academic achievement and motor skills for the children who attended >70% of classes. These predictions were assessed in a randomized controlled trial, which to our knowledge is the first to target Capoeira specifically.

## 2. Method

This randomized controlled trial was approved by the Ethics and Research Committee, University Hospital, UFRJ (CAAE 26338114.7.0000.5257) and was submitted to the Brazilian Registry of Clinical Trials (RBR-7kss24).

### 2.1. Participants

Children, 8–12 years of age, enrolled in a public school in Rio de Janeiro, Brazil, were randomized from the 3rd and 4th year of elementary school, paired by sex and academic achievement, to the experimental group (EG; which took Capoeira classes during the study) or to a wait-list control group (CG). Children in the CG took Capoeira classes the following semester and did not participate in any extracurricular activity during the study. An a priori sample size calculation was done using the software G*Power (version 3.1). The calculation was based on a previous study with Brazilian children investigating the effect of a physical education intervention on EFs and attention performance (Cardeal et al., 2013). Analysis was based on our desired statistical power level ($1 - \beta = 0.95$), significance level ($\alpha = 0.05$), and effect size ($ES = 0.49$), with a repeated-measures model (2 assessment time points [before and after] x 2 groups). The analysis indicated that a sample size of 36 participants would be needed.

The school is located within a low socioeconomic status district, and all the participants lived in the neighborhood around the school at the time of the study. The participants and their parents were informed about the study and signed consent forms authorizing participation in the study. Children diagnosed with the following were excluded from the sample: learning disorders, attention deficit hyperactivity disorder, intellectual disability, or auditory or visual deficiency. For comparing outcomes with the CG, children in the EG were separated into those with a high frequency of class attendance (HF EG, >70% of classes) and those with a low frequency of class attendance (LF EG, < 70% of classes).

### 2.2. Study procedures

Students performed the assessments in the following sequence both

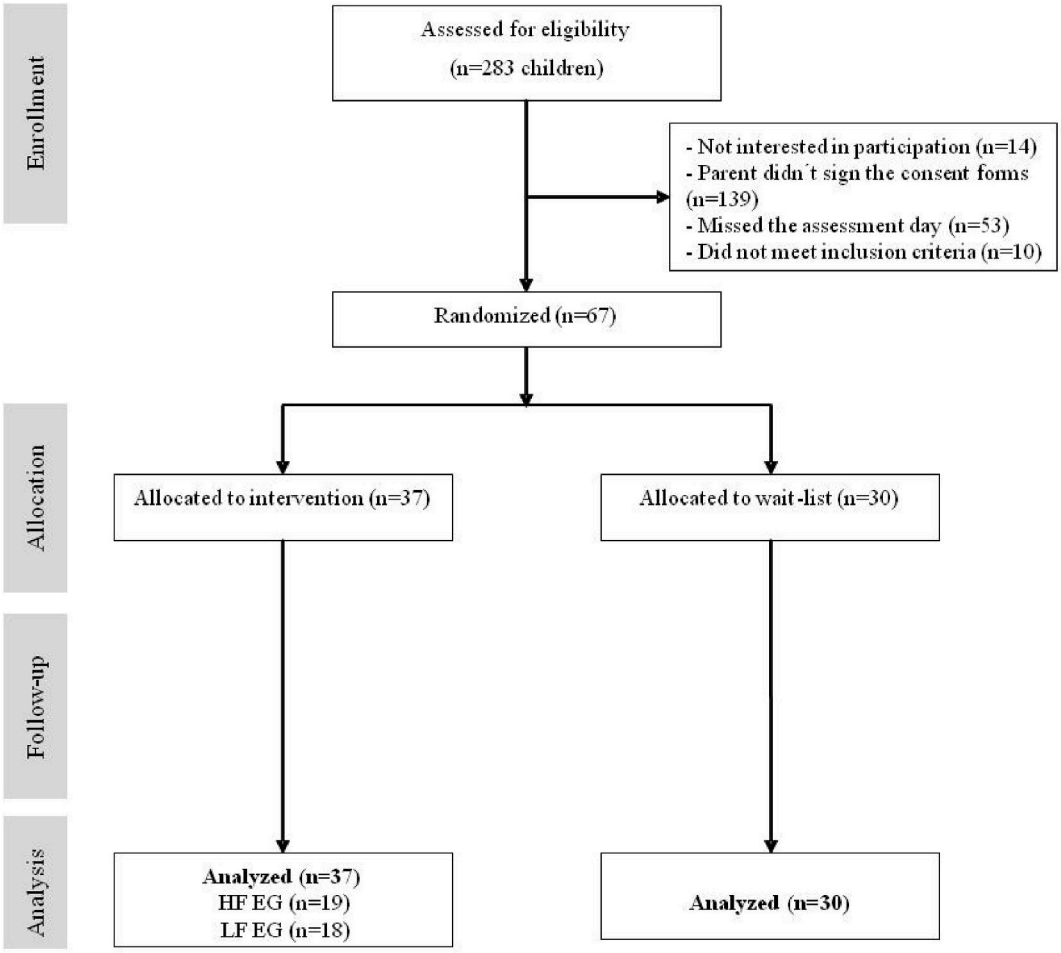


**Fig. 1.** Flow of participants from enrollment, allocation, follow-up to analysis.

before and after the intervention period, across two sessions on different days: On the first day, they took the reading subtest of the Academic Achievement Test (AAT) and core EF (working memory, cognitive flexibility and inhibitory control) assessments (Diamond, 2013). On the second day, the AAT writing and arithmetic subtests were administered, followed by tests of agility and motor coordination. The sessions were limited to 90 min. Tests were completed on an extra day when necessary. A psychologist (N.A.) and PE teachers (V.F. and A.D.) trained in the application of the instruments performed the neuropsychological and motor assessments, respectively.

### 2.3. Assessments

The neuropsychological evaluation of EFs consisted of the following subtests of the Wechsler Intelligence Scale for Children - Fourth Edition (WISC-IV): Digit Span Test - backwards (working memory); Letter-Number Sequencing (working memory); Matrix Reasoning (visuospatial reasoning); and the Stroop Test (inhibitory control). Scores were obtained on each subtest of the WISC-IV by adding weighted scores given to correct answers (Prifitera, Saklofske, & Weiss, 2008). We combined z-scores on all EF measures into an EF composite index score, calculated as follows: Composite Score = z-score (Digits Backward) + z-score (Matrix Reasoning) + z-score (Letter-Number Sequencing) + z-score (Stroop color - values in seconds multiplied by −1).

The Academic Achievement Test (AAT) (Stein, 1994) investigates fundamental abilities needed for academic achievement. It consists of three subtests: Writing, Arithmetic and Reading. The height and weight of all participants were assessed on the first day and used to calculate a body mass index (BMI) for each child. Eye-hand coordination was assessed with the Touch Test Disc (TTD), on which children had to touch a target circle with their dominant hand and come back to the initial circle, completing 25 correct cycles as fast as possible (Gobbi, Vilar, & Zago, 2005). Also, a standardized agility test (five cycles of running back and forth in a 5-m space) (Gobbi et al., 2005) was administered. A detailed description of every instrument used in this study can be found in a previous publication from our research group (Fernandes et al., 2016).

### 2.4. Intervention

Capoeira classes were carried out by a senior Capoeira master with extensive experience in teaching children. He was assisted by an instructor. The methodology comprised playful games integrated with Capoeira movements, which required constant motor and cognitive control. Visual, auditory, and multimodal commands were used, allowing for activities of high cognitive complexity and increasing difficulty. The classes were dynamic, involving simple multi-limb movements as well as specific Capoeira movements, individually or in pairs. Waiting time during class was minimized to favor aerobic conditioning. The technical content presented during the various classes comprised movements typical of Capoeira, such as “Ginga” (technique displacement), “esquivas” (defenses), rotating kicks, straight kicks, ground movements, and acrobatic movements. In the methodology employed, students adhered to the following stages of learning: First, there was ‘Experimentation’, which comprised indirect learning, based on broad descriptions of the movement or simple demonstration. In this stage, the

**Table 1**
Descriptive analysis of the EG and CG at baseline and results of statistical analyses of whether EG and CG differed on any variable at baseline.

| | HF EG | | LF EG | | CG | | *F (p)* |
|---|---|---|---|---|---|---|---|
| | N | *M (SD)* | N | *M (SD)* | N | *M (SD)* | |
| Sex (% female) | 19 | 53% | 18 | 50% | 30 | 50% | 0.02 (0.98) |
| Age in years | 19 | 10.13 (0.85) | 18 | 9.82 (0.91) | 30 | 10.42 (1.27) | 1.78 (0.18) |
| Height in cm | 19 | 1.41 (0.07) | 18 | 1.39 (0.07) | 30 | 1.43 (0.10) | 1.47 (0.24) |
| Weight in kg | 19 | 38.19 (9.20) | 18 | 34.51 (7.46) | 30 | 37.61 (11.23) | 0.89 (0.42) |
| BMI | 19 | 19.14 (3.58) | 18 | 17.78 (2.90) | 30 | 18.07 (3.45) | 0.78 (0.46) |
| **Executive Function:** | | | | | | | |
| Digits Backward | 19 | 5.32 (1.06) | 18 | 5.94 (1,59) | 28 | 5.11 (0.88) | 2.91 (0.06) |
| Letter-number seq. | 18 | 12.50 (3.03) | 13 | 13.00 (4.30) | 23 | 11.70 (4.48) | 0.48 (0.62) |
| Matrix Reasoning | 18 | 13.89 (3.61) | 13 | 15.15 (4.76) | 23 | 13.30 (4.47) | 0.78 (0.46) |
| Stroop Effect (s) | 19 | 14.26 (8.38) | 18 | 17.27 (6.18) | 29 | 16.07 (12.52) | 0.43 (0.66) |
| **Academic achievement:** | | | | | | | |
| AAT | 13 | 92.62 (10.00) | 13 | 91.38 (9.07) | 23 | 90.74 (15.99) | 0.09 (0.92) |
| **Motor measures:** | | | | | | | |
| Agility (s) | 18 | 25.89 (2.38) | 15 | 25.96 (2.46) | 26 | 24.66 (1.79) | 2.49 (0.09) |
| TTD (s) | 17 | 19.90 (3.37) | 15 | 19.28 (2.77) | 23 | 19.77 (2.96) | 0.18 (0.83) |

Notes: HF EG (High frequency experimental group [attended more of the Capoeira classes offered]); LF EG (Low frequency experimental group [attended fewer of the Capoeira classes offered]); CG (wait-list control group); BMI (body mass index); Letter-number seq. (Letter-number sequence); Stroop Effect (difference between congruent and incongruent conditions); AAT (Academic Achievement Test); TTD (Touch test disc); s (seconds) - the lower the values, the better the results. Variable in score values, except when described. One-way ANOVA - significant - $p < 0.05$.

students were able to show their individual interpretations and previous knowledge. Next, there was 'Explanation', during which techniques and movement functions were explained with feedback. The final stage was Practice, which included techniques repeated in game situations or in the Capoeira circle. Technical aspects were first approached indirectly within games, and later more directly. The musical and cultural content, as well as philosophical aspects, were emphasized during the classes, within the song lyrics and in the chats at the end of the classes. These Capoeira classes lasted 1 h and took place after school, three times a week for four consecutive months.

### 2.5. Statistical analysis

The Kolmogorov-Smirnov and the Levene tests were used to evaluated normality and homoscedasticity, respectively. The data met criteria for the use of parametric tests. For the comparison of the groups at baseline (HF EG, LF EG, and CG), a one-way ANOVA was performed. For evaluation of the effect of Capoeira on the main dependent variables of the study (EFs, academic achievement, and motor performance) we used analyses of covariance (ANCOVA) controlling for sex and age. Effect sizes (ES) were calculated ((Post-Pre)/Pooled SD) and the magnitude of the effect size was interpreted as suggested by Hopkins: <.20, Trivial; 0.21–0.60, Small; 0.61–1.20, Moderate; 1.21–2.00, Large; 2.01–4.00, Very Large; and >4.00, Nearly Perfect (Hopkins, Marshall, Batterham, & Hanin, 2009). The difference between ES (ΔES = ES HF EG – ES CG) and its respective confidence intervals (95% *CI*) were used to estimate the magnitude of the responses after intervention.

To assess the dose-response effect of Capoeira on EFs, we performed an independent *t*-test to compare the change in EFs (post-minus pre-test scores) of those who attended <70% of the Capoeira classes (LF EG) and those who attended ≥70% of the Capoeira classes (HF EG). In addition, a multiple linear regression adjusted for sex and age was performed between the number of Capoeira classes attended and the degree of improvement in EFs.

## 3. Results

After applying the eligibility criteria to the 283 children recruited, the 67 children who met criteria were randomized: 37 to the EG (Capoeira experimental group) and 30 to the CG (wait-list control group). Of the 37 children in the Capoeira program, 18 attended fewer than 70% of the sessions (LF EG), and therefore were excluded from comparisons with the CG, but were included in the dose-response analyses. Thus, 19 children (10 female) in the HF EG were compared with 30 children (15 female) in CG. Those categorized as HF EG attended on average 30 Capoeira classes of the 37 that were offered (81%). The participants' selection flowchart is presented in Fig. 1. At the beginning of the study, there was no significant difference between the groups (HF EG, LF EG and CG). The descriptive statistics are presented in Table 1.

Analyses of covariance (ANCOVA), that controlled for sex and age, showed a significant interaction (group X time) for TTD ($F_{(1.74)} = 4.971$, 0.029 [indicating the HF EG showed significantly more improvement over time than the CG]) but not for AAT ($F_{(1.66)} = 0.128$, 0.721) or any AAT subtest [Writing $F_{(1.66)} = 0.00$, p = 0.99; Arithmetic $F_{(1.66)} = 0.88$, $p = 0.35$; Reading ($F_{(1.66)} = 0.00$, $p = 0.94$], EF composite ($F_{(1.74)} = 1.479$, 0.228), or Agility ($F_{(1.83)} = 1.846$, p = 0.178). Furthermore, the analyses presented significant effects for Time (better performance at the post-test) on the motor variables of Agility ($F_{(1.83)} = 10.345$, $p < 0.00$) and TTD ($F_{(1.74)} = 7.431$; $p < 0.00$), but not for AAT ($F_{(1.66)} = 1.031$, p = 0.314) and the EF composite ($F_{(1.74)} = 0.498$, $p = 0.482$). Main effects for group (HF EG performing better) were observed on the EF Composite ($F_{(1.74)} = 4.443$, $p = 0.038$) and TTD ($F_{(1.74)} = 5.282$; $p = 0.024$), but not on AAT ($F_{(1.66)} = 0.439$, p = 0.510) or (Agility $F_{(1.83)} = 2.076$, $p = 0.153$). The differences between HF EG and CG are illustrated in Fig. 2.

Delta effect sizes differences between groups (high EG [n = 18] and CG [n = 22]) are illustrated in Fig. 3, showing significantly greater improvement for eye-hand coordination (ΔES = 0.97), the EF composite (ΔES = 0.59), agility (ΔES = 0.39), and academic achievement (ΔES = 0.37) in HF EG, as compared to CG.

Linear regression analysis suggests that the frequency of attending Capoeira classes may mediate the effects on EFs, since there was a small but positive dose-response relationship between the number of Capoeira classes attended and improvement on the EF composite (β = 0.12, *IC* = 0.02–0.22, p < 0.01), even when controlled by sex and age (β = 0.12, *IC* = 0.01–0.23, $p < 0.02$) as illustrated in Fig. 4. Moreover, *t*-test analysis of change scores (delta) in the EF composite showed a significant difference between HF EG and LF EG (HF EG = 0.79 (CI -4.47 - 3.49); LF EG = −0.74 (CI -3.99 - 4.03); t = −2.29, p < 0.03), showing that the HF EG improved more in EFs during the four months of the intervention than did the LF EG.

## 4. Discussion

In the present study, we found that attending Capoeira classes regularly for a period of 4 months significantly improved eye-hand coordination in children, and that effect was not influenced by age or sex. Moreover, a main effect for time was observed for agility, indicating that all groups improved in agility during the intervention period. This could reflect children's progressive improvement in motor skills with increasing age, motor skill benefits from PE classes and/or from children's play, or practice effects from having experienced this assessment at pre-test (Gallotta et al., 2017). Contrary to our hypothesis, no significantly greater improvements in EFs, agility, or academic

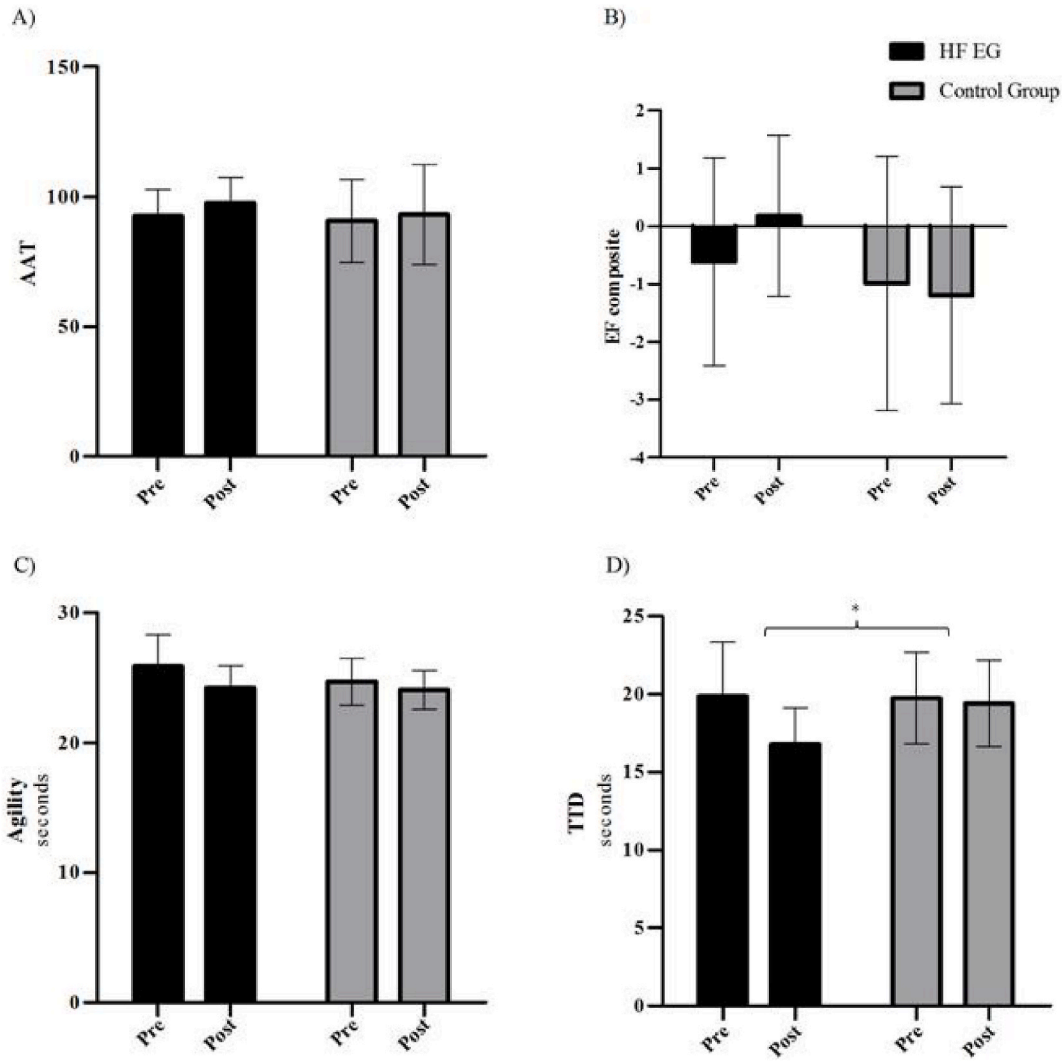


**Fig. 2.** HF EG (High Frequency Experimental Group); A) AAT (Academic Achievement Test); B) EF composite (Executive Function composite score); C) Agility; D) TTD (Touch Test Disc); ANCOVA controlling for sex and age. * Significant interaction (Group X time) ($p < 0.05$).

achievement were observed among children in the HF EG than among those in the CG. However, in addition to the moderate effect size shown for eye-hand coordination, we also observed that the intervention exerted a small positive effect on the EF composite. Importantly, a dose-response relationship was found between EF improvement and the number of Capoeira classes attended, i.e., there was significantly greater improvement on the EF composite among those in the HF EG than among those in the LF EG. This is consistent with the finding of Davis and colleagues (Davis et al., 2011) of a dose-dependent effect of aerobic exercise on EFs in children, although the doses used in their study differed in terms of session duration (40 min versus 20 min) rather than the number of sessions attended.

Although the effects sizes for EFs, agility, and academic achievement were modest, our results show some benefits of attending Capoeira classes. Modest benefits were not unexpected since previous research has shown that it may take 1–3 years for EFs improvements to translate into improved academic achievement (Holochwost et al., 2017; Lillard et al., 2017; Watts et al., 2018). The greatest benefits of our Capoeira intervention were found on the TTD, a timed eye-hand coordination test. Complex motor skills are closely related to executive functioning, both being mediated by the prefrontal cortex and cerebellum (Van der Fels et al., 2015). Eye-hand coordination tasks require focused attention and motor skills (Szabo, Neagu, Teodorescu, & Sopa, 2020). Those skills are demanded while playing Capoeira, since this activity promotes proprioceptive, tactile, visual, and auditory stimuli.

During Capoeira classes, emphasis was placed on the joy of performing the activity, with participants competing with their own best past performance rather than with others. Holistic characteristics were present as cultural and philosophical aspects throughout the intervention, from the understanding of the construction process of the berimbau to its multiple rhythms. The songs full of historical references, metaphors, and a multiplicity of alternative meanings extend this holistic approach to the informal conversation at the end of classes about behaviors observed inside and outside of the Capoeira circle.

The Capoeira master was supportive, conveying a strong belief in the participants and in the value of the activity, which has been reported to be important to see the best benefits from any activity on children's cognition (Álvarez-Bueno et al., 2017; Diamond & Ling, 2019b; Pesce et al., 2016). In fact, all the students who participated in >70% of the classes achieved technical proficiency that was sufficient for them to be awarded the first graduation in Capoeira. Our results are consistent with those obtained for a school taekwondo program in which EFs were challenged at increasingly demanding levels, and incorporated many of the characteristics mentioned above (Lakes & Hoyt, 2004). These findings are also consistent with the notion that for aerobic activity or motor skill challenges to benefit EFs, both of those aspects of physical activity must be present (Liu et al., 2018; Marchetti et al., 2015).

Some of the limitations of this study are related to its ecological

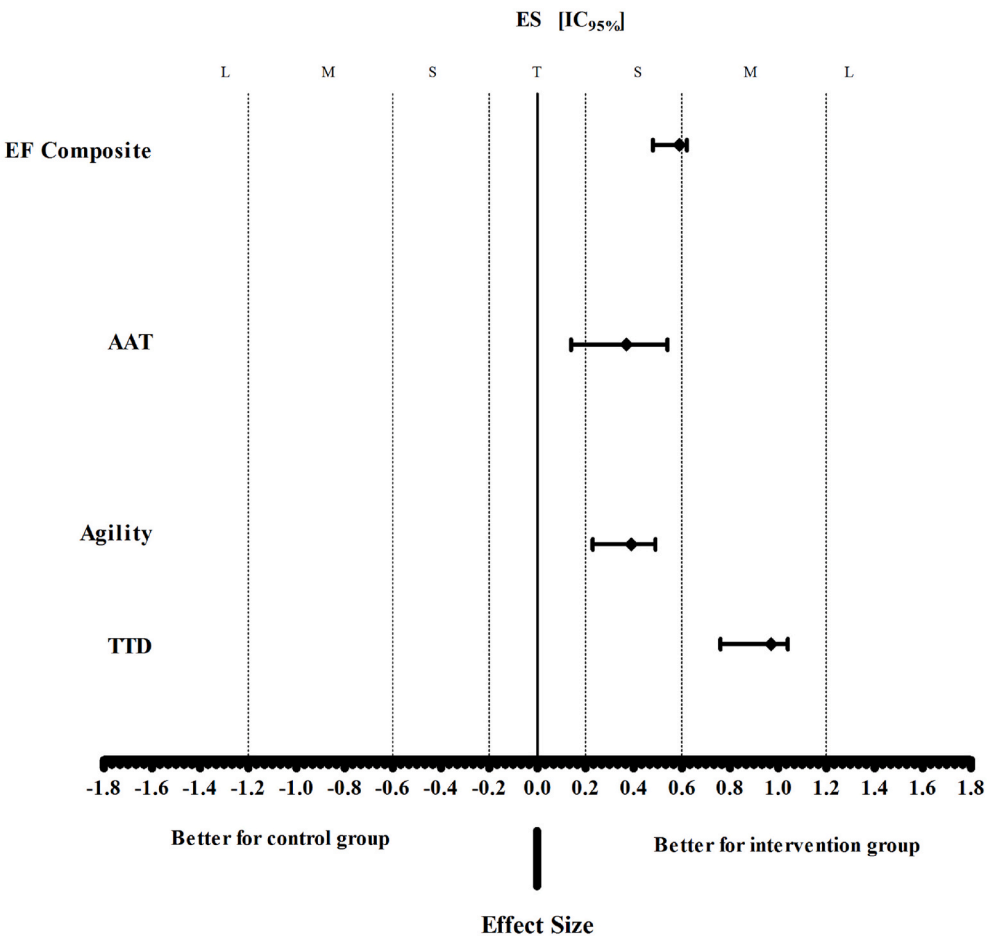


**Fig. 3.** Scores of ΔES (ΔES = effect size high frequency experimental group – effect size control group); Effect size - T: trivial (0.0–0.2); S: small (>0.2–0.6); M: moderate (>0.6–1.2); L: large (>1.2–2.0); EF Composite (Executive Functions Composite Score), ES: HF EG 0.49 and CG -0.10; AAT (Academic Achievement Test), ES: HF EG 0.50 and CG 0.37; Agility, ES: 0.80 HF EG and CG 0.41; TTD (Touch Test Disc), ES: HF EG 1.07 and CG 0.11.

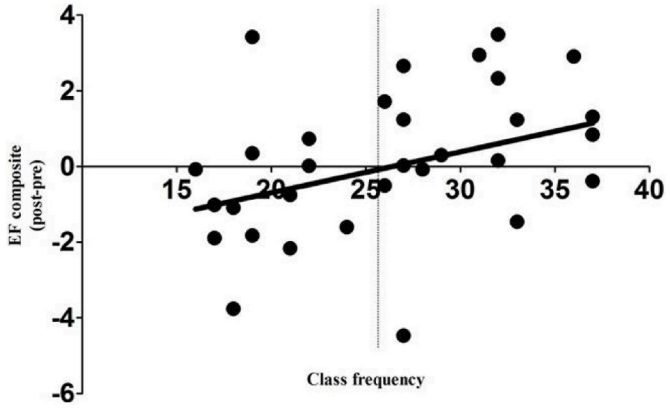


**Fig. 4.** Correlation between the number of classes of Capoeira attended and the delta (post - pre) for EF composite ($R^2 = 0.14$, $p = 0.01$). The vertical dotted line represents the threshold of 70% of frequency (≥26 lessons).

validity. The public school where the study took place is located in a community in Rio de Janeiro named "The City of God", that suffers from a lack of basic citizenship needs and high rates of criminality (Ruediger, 2017). In low socioeconomic communities in Brazil, this situation is aggravated by the increasing trend toward single-parent homes (Ayllón & Ferreira-Batista, 2015), making it more difficult for the parents to meet their work demands and at the same time participate in their children's school life. The low levels of parental involvement in school activities presented a problem in enrolling students in the study because of the difficulty in contacting parents to explain the importance of children's assiduity, and for them to sign the consent form. This helps explain why almost half of the participants in the Capoeira intervention failed to attend at least 70% of the classes. Despite these difficulties and the less-than-perfect Capoeira class attendance among the participants, significant benefits were still identified.

Another important limitation relates to potential selection bias. Children with higher SES backgrounds, children with more social support from parents and peers, and children who perform better at school are probably more likely to attend extracurricular activities compared with children with low SES, without social support, and low school performance. In the present study, we only assessed low SES participants, and differences in parental support between groups were not measured. So, further studies are needed to disambiguate this issue.

The neurophysiologic effects of exercise on cognition might be related to its intensity and duration (Hillman, Erickson, & Kramer, 2008). Therefore, the use of heart rate monitors or a pedometer would have provided important information. Studies with larger sample sizes, a Capoeira intervention lasting at least a full school year, better rates of attendance, and longer longitudinal follow-ups are needed to explore the full extent of Capoeira's potential to improve children's EFs and academic performance. Indeed, to understand the importance of different types of physical exercise on children's cognition, future studies should compare interventions with different levels of cognitive and social engagement, motor complexity, intensity, and duration.

Likewise, psychological and behavioral outcomes such as self-esteem and self-confidence should be assessed, as these would be important outcomes in their own right, and may be important to achieve optimal EF outcomes and best academic performance.

The improvement in eye-hand coordination related to Capoeira practice also deserves further scrutiny. The positive correlation between the practice of open skill sports (i.e., tennis, soccer, and martial arts), complex motor skills, and EFs has been described in the literature (Formenti et al., 2021; Van der Fels et al., 2015). Similar effects may be observed in response to other activities able to stimulate the overall state of awareness, visuospatial attention, mood, and mental health. In this sense, Capoeira seems to stimulate eye-hand coordination holistically, combining holistic movement practice and open skill task characteristics.

Another caveat worth mentioning is whether the moderate results observed here reflect a meaningful functional difference in EFs, as measured in children's everyday life. Future studies should attempt to measure the overall impact of Capoeira practice on real-life children's development, including long-term changes in health, SES, and academic status (Moffitt et al., 2011).

Despite its limitations, the present study is noteworthy for its innovative design, for being the first to quantitatively evaluate the effects of Capoeira classes on cognition, and for being one of the few studies to assess possible EF benefits from an open-task exercise program. It adds to our understanding of what characteristics exercise programs should have if they are to be beneficial for cognitive and psychological development (Diamond & Ling, 2019b; Pesce et al., 2016). Capoeira classes are becoming more commonly offered in preschool and school settings in Brazil, promoting the development of pedagogic strategies that address the demands of teaching young children (Silva & Heine, 2008).

In conclusion, our results suggest that Capoeira promotes positive effects on eye-hand motor coordination and may promote dose-dependent improvements in children's EFs. The present study highlights the need for further studies to determine the potential advantages of adopting Capoeira as a holistic movement practice for children, given its many positive characteristics.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## References

Alesi, M., Bianco, A., Luppina, G., Palma, A., & Pepi, A. (2016). Improving children's coordinative skills and executive functions: The effects of a football exercise program. *Perceptual & Motor Skills, 122*(1), 27–46. https://doi.org/10.1177/0031512515627527

Almeida, B. (1993). *Capoeira, a Brazilian art form: History, philosophy, and practice.* North Atlantic Books.

Álvarez-Bueno, C., Pesce, C., Cavero-Redondo, I., Sánchez-López, M., Martínez-Hortelano, J. A., & Martínez-Vizcaíno, V. (2017). The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis. *Journal of the American Academy of Child & Adolescent Psychiatry, 56*(9), 729–738. https://doi.org/10.1016/j.jaac.2017.06.012

Assunção, M. R. (2005). *Capoeira : The history of an afro-Brazilian martial art* (p. 267).

Ayllón, S., & Ferreira-Batista, N. N. (2015). 'Mommy, I miss daddy'. The effect of family structure on children's health in Brazil. *Economics and Human Biology, 19*, 75–89. https://doi.org/10.1016/j.ehb.2015.08.001

Best, J. R. (2010). Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review, 30*(4), 331–351. https://doi.org/10.1016/j.dr.2010.08.001

Boucard, G. K., Albinet, C. T., Bugaiska, A., Bouquet, C. A., Clarys, D., & Audiffren, M. (2012). Impact of physical activity on executive functions in aging: A selective effect on inhibition among old adults. *Journal of Sport & Exercise Psychology, 34*(6), 808–827. https://doi.org/10.1123/jsep.34.6.808

Cardeal, C. M., Pereira, L. A., Da Silva, P. F., De França, N. M., Silva, P. F., & França, N. M. (2013). Efeito de um programa escolar de estimulação motora sobre desempenho da função executiva e atenção em crianças. *Motricidade, 9*(3), 44–56. https://doi.org/10.6063/motricidade.9(3).762

Davis, C. L., Tomporowski, P. D., McDowell, J. E., Austin, B. P., Miller, P. H., Yanasak, N. E., et al. (2011). Exercise improves executive function and achievement and alters brain activation in overweight children: A randomized, controlled trial. *Health Psychology, 30*(1), 91–98. https://doi.org/10.1037/a0021766

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science, 21*(5), 335–341. https://doi.org/10.1177/0963721412453722

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A. (2015). Effects of physical exercise on executive functions: Going beyond simply moving to moving with thought. *Annals of Sports Medicine and Research, 2*(1), 1011. http://www.ncbi.nlm.nih.gov/pubmed/26000340.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience, 18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Diamond, A., & Ling, D. S. (2019a). Aerobic-exercise and resistance-training interventions have been among the least effective ways to improve executive functions of any method tried thus far. *Developmental Cognitive Neuroscience, 37*, 100572. https://doi.org/10.1016/j.dcn.2018.05.001

Diamond, A., & Ling, D., S. (2019b). Review of the evidence on, and fundamental questions about, efforts to improve executive functions, including working memory. In J. Novick, M. Bunting, F., M. Dougherty, R., & R. Engle, W. (Eds.), *Cognitive and Working Memory Training* (March, pp. 143–431). NYC, NY: Oxford University Press. ISBN:978-0199974467.

Fernandes, V., R., Ribeiro, M., L. Scipião, Melo, T., Maciel-Pinheiro, P., de Tarso, Guimarães, T., T., Araújo, N., B., … Deslandes, A., C. (2016). Motor Coordination Correlates with Academic Achievement and Cognitive Function in Children. *Frontiers in Psychology, 7*(MAR), 1–8. https://doi.org/10.3389/fpsyg.2016.00318

Formenti, D., Trecroci, A., Duca, M., Cavaggioni, L., D'Angelo, F., Passi, A., et al. (2021). Differences in inhibitory control and motor fitness in children practicing open and closed skill sports. *Scientific Reports, 11*(1), 4033. https://doi.org/10.1038/s41598-021-82698-z

Gallahue, D. L., Ozmun, J. C., & Goodway, J. C. (2013). Compreendendo o desenvolvimento motor : Bebês, crianças, adolescentes e adultos. *AMGH Editora Ltda, 7*, 19–481.

Gallotta, M. C., Emerenziani, G. P., Iazzoni, S., Iasevoli, L., Guidetti, L., & Baldari, C. (2017). Effects of different physical education programmes on children's skill- and health-related outcomes: A pilot randomised controlled trial. *Journal of Sports Sciences, 35*(15), 1547–1555. https://doi.org/10.1080/02640414.2016.1225969

Gobbi, Sebastião, Vilar, Rodrigo, & Zago, Anderson, S (2005). *Educação Física no ensino superior - bases teórico-práticas do condicionamento físico* (1st). Guanabara Kooga.

Hillman, Charles, H, Erickson, Kirk, I, & Kramer, Arthur, F (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews Neuroscience, 9*(1), 58–65. https://doi.org/10.1038/nrn2298

Holochwost, S. J., Propper, C. B., Wolf, D. P., Willoughby, M. T., Fisher, K. R., Kolacz, J., et al. (2017). Music education, academic achievement, and executive functions. *Psychology of Aesthetics, Creativity, and the Arts, 11*(2), 147–166. https://doi.org/10.1037/aca0000112

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*(1), 3–13. https://doi.org/10.1249/MSS.0b013e31818cb278

Lakes, K. D., & Hoyt, W. T. (2004). Promoting self-regulation through school-based martial arts training. *Journal of Applied Developmental Psychology, 25*(3), 283–302. https://doi.org/10.1016/j.appdev.2004.04.002

Lewis, J. L. (1994). Ring of liberation: Deceptive discourse in Brazilian Capoeira. *American Ethnologist, 21*(4), 1091–1092. https://doi.org/10.1525/ae.1994.21.4.02a02050

Lillard, A. S., Heise, M. J., Richey, E. M., Tong, X., Hart, A., & Bray, P. M. (2017). Montessori preschool elevates and equalizes child outcomes: A longitudinal study. *Frontiers in Psychology, 8*, 1783. https://doi.org/10.3389/fpsyg.2017.01783

Liu, J.-H., Alderman, B. L., Song, T.-F., Chen, F.-T., Hung, T.-M., & Chang, Y.-K. (2018). A randomized controlled trial of coordination exercise on cognitive function in obese adolescents. *Psychology of Sport and Exercise, 34*, 29–38. https://doi.org/10.1016/j.psychsport.2017.09.003

Marchetti, R., Forte, R., Borzacchini, M., Vazou, S., Tomporowski, P. D., & Pesce, C. (2015). Physical and motor fitness, sport skills and executive function in adolescents: A moderated prediction model. *Psychology, 6*(14), 1915–1929. https://doi.org/10.4236/psych.2015.614189

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America, 108*(7), 2693–2698. https://doi.org/10.1073/pnas.1010076108

Moreau, D., & Conway, A. R. A. (2013). Cognitive enhancement: A comparative review of computerized and athletic training programs. *International Review of Sport and Exercise Psychology, 6*(1), 155–183. https://doi.org/10.1080/1750984X.2012.758763

Moreau, D., & Conway, A. R.a. (2014). The case for an ecological approach to cognitive training. *Trends in Cognitive Sciences, 18*(7), 334–336. https://doi.org/10.1016/j.tics.2014.03.009

Moreau, D., Morrison, A. B., & Conway, A. R. A. (2015). An ecological approach to cognitive enhancement: Complex motor training. *Acta Psychologica, 157*, 44–55. https://doi.org/10.1016/j.actpsy.2015.02.007

Moreira, S. R., Teixeira-Araujo, A. A., Oliveira Dos Santos, A., & Simões, H. (2016). Ten weeks of capoeira progressive training improved cardiovascular parameters in male practitioners. *The Journal of Sports Medicine and Physical Fitness, 53*(3), 289–298. https://doi.org/10.23736/S0022-4707.16.06030-8

Pesce, C., Croce, R., Ben-Soussan, T. D., Vazou, S., McCullick, B., Tomporowski, P. D., et al. (2016). Variability of practice as an interface between motor and cognitive development. *International Journal of Sport and Exercise Psychology, 17*(2), 133–152. https://doi.org/10.1080/1612197X.2016.1223421

Pesce, C., Marchetti, R., Forte, R., Crova, C., Scatigna, M., Goudas, M., et al. (2016). Youth life skills training: Exploring outcomes and mediating mechanisms of a group-randomized trial in physical education. *Sport, Exercise, and Performance Psychology, 5*(3), 232–246. https://doi.org/10.1037/spy0000060

Pesce, C., Vazou, S., Benzing, V., Álvarez-Bueno, C., Anzeneder, S., Mavilidi, M. F., et al. (2021). Effects of chronic physical activity on cognition across the lifespan: A systematic meta-review of randomized controlled trials and realist synthesis of contextualized mechanisms. *International Review of Sport and Exercise Psychology*, 1–39. https://doi.org/10.1080/1750984X.2021.1929404

Pontzer, H. (2017). Economy and endurance in human evolution. *Current Biology, 27*(12), R613–R621. https://doi.org/10.1016/j.cub.2017.05.031

Prifitera, A., Saklofske, D. H., & Weiss, L. G. (2008). *WISC-IV clinical assessment and intervention*. Elsevier. Elsevier.

Ruediger, M. A. (2017). In DAPP (Ed.), *Education on target: The effects of armed violence on the classrooms* (1st ed.). FGV.

Schmidt, M., Jäger, K., Egger, F., Roebers, C. M., & Conzelmann, A. (2015). Cognitively engaging chronic physical activity, but not aerobic exercise, affects executive functions in primary school children: A group-randomized controlled trial. *Journal of Sport & Exercise Psychology, 37*(6), 575–591. https://doi.org/10.1123/jsep.2015-0069

Scudder, M. R., Lambourne, K., Drollette, E. S., Herrmann, S. D., Washburn, R. A., Donnelly, J. E., et al. (2014). Aerobic capacity and cognitive control in elementary school-age children. *Medicine & Science in Sports & Exercise, 46*(5), 1025–1035. https://doi.org/10.1249/MSS.0000000000000199

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology, 94*(2), 143–174. https://doi.org/10.1348/000712603321661859

Silva, G. de O., & Heine, V. (2008). Capoeira: Um instrumento psicomotor para a cidadania. In *São Paulo: Phorte. Phorte*.

Singh, A. S., Saliasi, E., van den Berg, V., Uijtdewilligen, L., de Groot, R. H. M., Jolles, J., et al. (2019). Effects of physical activity interventions on cognitive and academic performance in children and adolescents: A novel combination of a systematic review and recommendations from an expert panel. *British Journal of Sports Medicine, 53*(10), 640–647. https://doi.org/10.1136/bjsports-2017-098136

Singh, A., Uijtdewilligen, L., Twisk, J. W. R., Mechelen, W. van, & Chinapaw, M. J. M. (2012). Physical activity and performance at school. *Archives of Pediatrics and Adolescent Medicine, 166*(1), 49. https://doi.org/10.1001/archpediatrics.2011.716

Stein, L. M. (1994). *TDE: Teste de desempenho escolar: Manual para aplicação e interpretação*. Casa do Psicólogo.

Szabo, D. A., Neagu, N., Teodorescu, S., & Sopa, I. S. (2020). Eye-hand relationship of proprioceptive motor control and coordination in children 10-11 years old. *Health, Sports & Rehabilitation Medicine, 21*(3), 185–191. https://doi.org/10.26659/pm3.2020.21.3.185

Van der Fels, I. M. J., te Wierike, S. C. M., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. *Journal of Science and Medicine in Sport, 18*(6), 697–703. https://doi.org/10.1016/j.jsams.2014.09.007

Vergeer, I., & Biddle, S. (2021). Mental health, yoga, and other holistic movement practices: A relationship worth investigating. *Mental Health and Physical Activity, 21*, Article 100427. https://doi.org/10.1016/j.mhpa.2021.100427

Watts, T. W., Gandhi, J., Ibrahim, D. A., Masucci, M. D., & Raver, C. C. (2018). The Chicago school readiness project: Examining the long-term impacts of an early childhood intervention. *PLoS One, 13*(7), Article e0200144. https://doi.org/10.1371/journal.pone.0200144