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Improvement of Executive Function Through Cognitively Challenging Physical Activity with Nonlinear Pedagogy In Elementary Schools

Mejora de la función ejecutiva a través de actividad física cognitivamente desafiante con pedagogía no lineal en escuelas primarias

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Abstract. This study investigated the effects of cognitively challenging with nonlinear pedagogical games on the executive functions and situational interests of students in physical education. Participants were 145 fifth and sixth-grade students (74 boys, 71 girls) from four elementary schools. This acute investigation, which included a physical education session, utilized a quasi-experimental design with four groups, repeated measures, and cross-over. After the post-test, one fifth- and one sixth-grade class from each school was randomly assigned to Group 1 with cognitively challenging nonlinear pedagogy games, Group 2 with a session for teaching soccer skills, Group 3 with a session for teaching track and field skills, and Group 4 control group, all the group with cognitively challenging physical with activity nonlinear pedagogy games. Included were pre- and post-test measures of executive functioning and a post-test assessment of situational interest. Students in Group 1 who engaged in cognitively challenging physical activity with nonlinear pedagogy games increased their executive function scores ($t(39) = -19.75$, $p < 0.001$, $d=1.82$) more than students who participated in sessions with group 2 soccer ($t(33) = -3.14$, $p=0.005$), group 3 track and field skills ($t(38) = -0.98$, $p=0.325$) and those group 4 the control group ($t(32) = -0.68$, $p=0.523$). The positive effects on the executive functions of students were duplicated when the cognitively demanding physical activity with nonlinear pedagogy games session was administered to the control group on the waiting list Students who participated in the soccer skills session showed some improvements in their executive functions. Students who participated in cognitively challenging physical nonlinear games scored higher on novelty than those who participated in soccer or track and field. These findings confirm the efficacy of cognitively challenging physical activity using nonlinear games in stimulating the executive functions of students in physical education.
Key words: physical activity, nonlinear pedagogy, situational interest, cognitive engagement, design fluency

Resumen. Este estudio investigó los efectos del desafío cognitivo con juegos pedagógicos no lineales sobre las funciones ejecutivas y los intereses situacionales de los estudiantes de educación física. Los participantes fueron 145 estudiantes de quinto y sexto grado (74 niños, 71 niñas) de cuatro escuelas primarias. Esta aguda investigación, que incluyó una sesión de educación física, utilizó un diseño cuasi-experimental con cuatro grupos, medidas repetidas y cruzadas. Después de la prueba posterior, una clase de quinto y sexto grado de cada escuela se asignó aleatoriamente al Grupo 1 con juegos de pedagogía no lineal cognitivamente desafiantes, al Grupo 2 con una sesión para enseñar habilidades de fútbol, y al Grupo 3 con una sesión para enseñar atletismo. Habilidades de campo y el Grupo 4 (grupo de control de la lista de espera) con juegos de pedagogía no lineal física y cognitivamente desafiantes. Se incluyeron medidas previas y posteriores a la prueba del funcionamiento ejecutivo y una evaluación posterior a la prueba del interés situacional. Los estudiantes del grupo 1 que participaron en actividades físicas cognitivamente desafiantes con juegos de pedagogía no lineal aumentaron sus puntajes de función ejecutiva ($t(39) = -19{,}75$, $p < 0{,}001$, $d=1{,}82$) más que los estudiantes que participaron en sesiones de fútbol del 2 ($t(33) = -3{,}14$, $p=0{,}005$), habilidades de atletismo del grupo 3 ($t(38) = -0{,}98$, $p=0{,}325$) y del grupo 4 en lista de espera para el control ($t(32) = -0{,}68$, $p=0{,}523$). Los efectos positivos sobre las funciones ejecutivas de los estudiantes se duplicaron cuando se administró la sesión de actividad física cognitivamente exigente con juegos de pedagogía no lineal al grupo de control en lista de espera. Los estudiantes que participaron en la sesión de habilidades futbolísticas mostraron algunas mejoras en sus funciones ejecutivas. Los estudiantes que participaron en juegos físicos no lineales cognitivamente desafiantes obtuvieron puntajes más altos en novedad que aquellos que participaron en fútbol o atletismo. Estos hallazgos confirman la eficacia de la actividad física cognitivamente desafiante utilizando juegos no lineales para estimular las funciones ejecutivas de los estudiantes de educación física.
Palabras clave: Actividad física, pedagogía no lineal, interés situacional, compromiso cognitivo, fluidez en el diseño.

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Introduction

Physical education emphasises the psychomotor, social, and cognitive development of students. Students can acquire the skills, knowledge, and attitudes necessary for obtaining and sustaining a level of physical activity and fitness that is beneficial to their health through physical education (Del Val Martín et al., 2023; Invernizzi et al., 2019). High levels of motor skills in younger years are indicative of greater cognitive development and academic success (Selzam et al., 2017). To accomplish all of these objectives, it is necessary to implement successful programmes with the proper content. This study focused on cognitively challenging physical activity with nonlinear pedagogical games that are suitable for improving the overall development of pupils in physical education (Edwards et al., 2017; Vazou et al., 2019). These nonlinear games engage students in attractive, demanding, and entertaining physical activity, stimulating their executive processes, enhancing their motor and coordination skills, and facilitating their education while they have fun (Práxedes et al., 2018; Rahman et al., 2019). Nonetheless, scientific research proving their effectiveness is essential.

Nonlinear pedagogy is a powerful paradigm for understanding cognitive processes by designing effective learning, coaching, and training programmes in sports and

physical education. This type of pedagogy of complexity inherent in learning has one focus on improving the cognitive development of learners, the learning environment, and the teacher or trainer as a complex interacting system (Lee et al., 2017). In this nonlinear pedagogy, the focus is on ecological dynamics (Laubmeier et al., 2020; Rudd et al., 2021). Ecological dynamics is a theoretical perspective that views the cognitive skills of constraints at the perceptual-cognitive interaction level. From this perspective, the acquisition of cognitive skills in individual and team sports is based on continuous interaction between individual learners and application in sports that approximate real environments (Ovens et al., 2013).

Recent studies on the relationship between physical activity and cognitive development have centred on executive functions (Kontostavlou & Drigas, 2022; Schmidt et al., 2017). Executive functions are a group of interrelated, higher-order cognitive processes responsible for the cognitive flexibility and adaptability of goal-directed behaviour (Friedman & Robbins, 2022). These processes are particularly activated when concentration and focus are required in unexpected, challenging, and intricate settings (Moore et al., 2019). It takes effort to employ executive functions since it is more difficult to plan what to do next than to continue what you are doing or to give in to temptation than to resist it. There is widespread agreement that inhibition, working memory, and cognitive flexibility are the three main executive functions (Visier-Alfonso et al., 2021). Inhibition enables pupils to manage their attention, conduct, ideas, and emotions in order to take the most appropriate actions (Valverde, 2021). For instance, pupils may need to block an automatic response because the environment has changed or refrain from behaving impulsively so that to behave effectively in the future. Working memory refers to the short-term storage and manipulation of information required for effective action, and it assists pupils in translating instructions into action plans, considering alternatives, and establishing relationships between pieces of knowledge. Cognitive flexibility enables pupils to change their focus between tasks, alter their viewpoints or problem-solving strategies, and adapt to new demands, rules, or priorities (Kolovelonis et al., 2023). For instance, cognitive flexibility enables pupils to modify problem-solving criteria if the current criteria are ineffective.

Executive functions are critical for mental and physical health, school and life success, academic achievement (Oberer et al., 2018), and school preparedness (Azhyppo et al., 2018). For example, positive connections were identified between the executive functions of children and adolescents and their performance on reading and mathematical activities (Bailey et al., 2018). Even after controlling for other significant indicators of academic achievement, such as socioeconomic position and general cognitive abilities, the positive connections between executive functions and academic achievement appear to be significant (Boonk et al., 2018).

Self-regulated learning and effective metacognitive control are also correlated with executive functions (Boonk et al., 2018). The foundational role of executive functions in the development of self-regulated learning is very important (Laxdal et al., 2020). This is because self-regulated learning has many positive effects on education, including in physical education. In the context of athletics, correlations between executive functions and performance have been established. In addition, executive functions predicted the success of young top soccer players and mediated the relationship between physical skill and academic achievement (Knöllner et al., 2022).

In recognition of the significant educational outcomes associated with executive functions, the focus of research has been on creating effective treatments for increasing executive functions (Peng & Kievit, 2020). Recently systematic review included 179 intervention trials including computerized and non-computerized cognitive training, school programs, physical activities, and mindfulness techniques to improve executive functions (Legemaat et al., 2021; Veloso et al., 2020). Long-term or acute physical activity can improve executive skills, according to a significant finding in this field of study (Padial-Ruz et al., 2022; Watson et al., 2017). A recent meta-analysis, for instance, revealed positive effects of physical activity on executive functions, attention, and academic achievement in pre-adolescent, with the greatest results anticipated for interventions focusing on continued regular physical activity over many weeks (Biddle et al., 2019; Rodriguez-Ayllon et al., 2019). However, the effects of different types of physical activity on executive processes remains largely unstudied.

Several preliminary indications of this strategy's efficacy have been documented. When students engaged in cognitively complex physical activity experiences, motor coordination training, and novel, challenging, diverse, but not extremely repetitive and automated tasks, their executive functions improved (Pesce et al., 2019). Situation in physical education program that included floorball and basketball and had a high level of physical exertion and cognitive engagement improved the executive functions of elementary pupils more than an aerobic program and the control condition (Song et al., 2022). Furthermore, after a six-month intervention filled with cognitively demanding activities and a sport program enriched with cognitive stimulation, beneficial effects on the executive functions of pupils were observed.

Physical education is regarded as a situation that can play a crucial role in the development of executive functions in pupils (de Bruijn et al., 2018). Physical education programs can reach the vast majority of school-aged children, boosting their effectiveness (Cenizo-Benjumea et al., 2022; Gu et al., 2018). However, actual study evidence in this area is often scant). Interventions done in other similar contexts (e.g., sport or physical activity) may differ in scope and substance, with a primary emphasis on boosting physical

activity or maximizing sport performance (Robertson et al., 2019). Physical education, on the other hand, should emphasize the complete development of kids by encouraging physical activity, teaching motor and sport skills, and giving them with good experiences.

Nonlinear pedagogy is a potent paradigm for understanding human movement through the creation of effective learning, coaching, and training programs in sports, physical education, and exercise (Raposo et al., 2019; Stone et al., 2021). Learning's inherent complexity pedagogy focuses on the cognitive, the learning environment, and the teacher or trainer as a complex system of interactions. The emphasis of this nonlinear teaching is on ecological dynamics (Lozano et al., 2017). Ecological dynamics is a theoretical viewpoint that examines the perceptual-cognitive interplay of limiting cognitive skills (Gómez-Criado & Valverde-Esteve, 2020; Ovens et al., 2013). According to this view, the acquisition of skill in individual and team sports is dependent on continuing interactions between individual learners and the application of more particular sports.

This study investigated the effects of a single physical education session that included cognitively challenging physical activity with nonlinear pedagogy games on the executive functions and situational interest of students. These effects were compared to those of a session in which open skills were taught and a session in which closed skills were taught. Involved were also comparisons between these three groups and a waiting-list control group. In order to replicate the potential effects of cognitively demanding physical activity with nonlinear pedagogy games on students' executive functions, the session with nonlinear pedagogy games was also administered to the control group on the waiting list following the post-test. It was hypothesized that students who participated in cognitively challenging physical activity with nonlinear pedagogy games would improve their executive function scores from pre- to post-test, outperforming the control group students on the waiting list who would also improve their scores after receiving the intervention. Due to the lack of prior evidence, no particular hypotheses were developed to compare the effects of the three groups with varied content (i.e., physical activity games, soccer skills, and track and field skills) on the executive functions and situational interest of students

The remaining sections of this paper are organized as follows: Section 2 examines all materials and methods, Section 3 presents the findings, Section 4 discusses the findings, and Section 5 summarizes the findings with some recommendations for future research.

Method

Subjects / Participants

Participants were 145 students (Mage=9.96, SD =0.63, 74 boys, 71 girls) from four fifth-grade (67 students) and four sixth-grade (78 students) classes of four elementary schools. Random assignment of one fourth- and one fifth-grade class from each school to each of the four study groups was performed. Group 1 consisted of 40 students (20 boys, 20 girls), Group 2 of 32 students (17 boys, 15 girls), Group 3 of 36 students (18 boys, 18 girls), and Group 4 of 37 students (20 boys, 17 girls). No student denied participation or dropped out of class. This study recruited typical Indonesia state elementary schools with open sport facilities, including basketball and volleyball outdoor courts and a schoolyard for additional sport activities. Physical education in Indonesia is coeducational, mandated, and taught by physical education teachers in three 45-minute sessions per week for fifth-graders and two 45-minute sessions per week for sixth-graders. The fifth and sixth grade physical education curriculum includes the major team sports (i.e. basketball, volleyball, soccer, and handball), individual sports (i.e. track and field and gymnastics) and traditional dance. In Indonesia, the primary objective of physical education for all grade levels is to encourage lifelong physical activity and quality of life among students. Physical education at the primary level focuses primarily on developing pupils' motor and sport abilities and fostering their cognitive and social development through age-appropriate physical activities.

Study organization

In this acute field experiment, which included a single physical education session, a four-group, repeated-measures, cross-over quasi-experimental method was used. Four groups were specifically involved: a) Group 1 with cognitively challenging physical activity with nonlinear pedagogy games, b) Group 2 with soccer skills, c) Group 3 with track and field skills, and d) Group 4, a waiting-list control group without physical education between the first and second measures and with cognitively challenging physical activity with nonlinear pedagogy games after the second measure. There were pre- and post-test measures for executive functioning, as well as a post-test measure for situational interest.

Instrumentation

The design fluency test. The design fluency test (Heled et al., 2012) is part of the Delis-Kaplan Executive Function System, a battery of standardized tests with adequate psychometric qualities, including convergent and discriminant validity (Heled et al., 2012). This test has been previously used with young athletes (Vestberg et al., 2017). It has the advantages of being administered at the class level and resembling a game that children would enjoy playing (Baron, 2004). This test measures a student's ability to generate as many unique designs as possible in 60 seconds by connecting dots with a pencil using four consecutive straight lines while avoiding repeated patterns. The examination consisted of three conditions and a sheet with 35 square boxes containing unorganized arrays of dots for each condition. In the first condition, each box contained five solid dots, and students were required to create as many

unique designs as possible using four consecutive straight lines. In condition 2, each box contained five solid and five blank dots, and students were required to create original designs connecting only the blank dots. In condition 3, each box included five solid and five blank dots, and students were required to create innovative patterns by alternating between connecting solid and blank dots (starting either from a solid or a blank dot). In each circumstance, the students' scores were based on the number of correct and distinctive designs. The first condition measures design fluency, the second condition additionally measures response inhibition, and the third condition measures novel design generation while switching tasks (cognitive flexibility). A total score was also calculated by combining the scores in the three conditions (Heled et al., 2012).

Situational interest. The situational interest scale (Cabot & Facchin, 2023), used to assess the situational interest of students. This 19-item scale includes five situational interest dimensions: novelty (e.g., "what we did today was new to me"), immediate enjoyment (e.g., "what we did today was enjoyable for me"), exploration intention (e.g., "I wanted to analyze and gain a better understanding of what we were learning today"), attention demand (e.g., "I was focused on what we were learning"), and challenge (e.g., "what we were learning was difficult"). Each of these dimensions includes three components. In addition, a four-item global subscale of total interest (e.g., "what we were learning today seemed fun to me") was measured. On a five-point Likert scale ranging from one (strongly disagree) to five (strongly agree), each item was rated (strongly agree). This scale has been adapted in the Indonesian language (Quinlan, 2019) demonstrating sound psychometric properties including a good model fit of the sixth-factor solution, $\chi 2$ (138) =160.82, p=0.098, $\chi 2$ /df =1.37, NNFI =.960, CFI=.973, RMSEA =.035 (90% CI: .000–.065). For this study, the internal consistency (Cronbach's alpha) for novelty (.97), instant enjoyment (.87), exploration intention (.87), attention demand (.77), challenge (.71), and total interest (.84) was satisfactory.

Statistic analysis

Using a one-way MANOVA and a 2 (Grade) 2 (Gender) MANOVA, pre-test differences in the students' scores on the three conditions of the design fluency test between groups and between grades and gender were analyzed, respectively. The intervention effects were analyzed using a 4 (Group) 2 (Time) repeated measures MANOVA with the students' scores in the three conditions of the design fluency test as dependent variables, followed by separate univariate analyses for each test condition and comparisons of pre- to post-test scores within each group. In addition, a 4 (Group) 2 (Time) repeated measures ANOVA was performed, with the total score on the design fluency exam serving as the dependent variable. Group 4 (i.e., the waiting-list control group) was subjected to a repeated measures MANOVA with the three conditions of the design fluency test as dependent variables and the three times of measurement as the repeated measure factor, followed by respective univariate within group tests and pairwise comparisons between the three experimental conditions. A repeated measures ANOVA was also performed for all three measurements, with the total score on the design fluency test serving as the dependent variable. A one-way MANOVA was used to examine group differences in students' scores on the six situational interest subscales. Group 1 and Group 4 were analyzed as a single group because they participated in the same experimental session involving cognitively demanding physical activity with nonlinear pedagogy games. Effects sizes of partial $\eta 2$ and Cohen's d were also calculated (Alber et al., 2019).

Results

Preliminary analysis

Table 1 shows the means and standard deviations for each group's pre- and post-test scores in the three conditions, as well as the total score on the design fluency test. Table 2 shows the means, standard deviations, and correlations of post-test scores on the six subscales of the situational interest questionnaire for each group separately, as well as for the total sample. There were no differences between groups in the three design fluency test conditions prior to the test $F(9, 420)=0.45$, $p=0.292$, and in the total score, $F(3, 140)=1.96$, $p=0.123$. A nonsignificant grade and gender interaction, $F(3, 138)=0.57$, $p=0.638$, and a nonsignificant main effect for grade, $F(3, 138)=1.82$, $p=0.146$, and gender, $F(3, 138)=1.36$, $p=0.259$, were discovered in students' pre-test scores for the three design fluency test conditions.

Effects of the intervention on students' executive functions

To investigate the effects of the intervention on students' performance on the three conditions of the design fluency test, a 4 (Group) × 2 (Time) repeated measures MANOVA was conducted showing a significant Group × Time multivariate interaction, $F(9, 336) =15.72$, $p < 0.001$, $\eta 2=.248$. Univariate tests showed a significant Group × Time interaction for test condition 1, $F(3, 140) =27.29$, $p < 0.001$, $\eta 2=.359$, for test condition 2, $F(3, 140)=16.26$, $p < 0.001$, $\eta 2=.261$, and for test condition 3, $F(3, 140)=36.31$, $p < 0.001$, $\eta 2=.451$. In test condition 1, significant improvements from pre- to post-test were found for Group 1, $t(39) = -13.57$, $p < 0.001$, $d=1.75$, Group 2, $t(31) =-2.62$, $p =0.010$, $d=0.44$, and Group 3, $t(35) =-2.20$, $p=0.029$, $d=0.25$, but not for Group 4, $t(36) = -1.15$, $p=0.260$.

Table 1.
Means and standard deviations for pre- and post-test scores in the three conditions, as well as the total score on the design fluency test.

Variable	Group 1 & 4		Group 2		Group 3		Correlations				
	Post-Test		Post-test		Post-test		1	2	3	4	5
	M	SD	M	SD	M	SD					
1. Novelty	3.18	1.43	2.20[a]	1.37	2.18[a]	1.32	.37*	.23	.24*	.25*	.32*
2. Challenge	1.83	1.04	1.78	1.03	1.73	.90	-.01	-.04	.12	.00	-
3. Attention demand	4.12	0.84	4.04	1.04	4.02	.89	.56*	.58*	.53*	-	
4. Exploration intention	3.54	1.01	3.65	1.06	3.52	.90	.64*	.68*	-		
5. Instant enjoyment	3.85	0.94	4.10	.91	3.92	.97	.82	-			
6. Total interest	3.96	1.00	3.78	1.06	3.78	.85	-				

note: a Significant variations in comparison to Group 1 and 4, Group 1 and 4: cognitively challenging physical activity with nonlinear games; Group 2: soccer skills; Group 3: track and field skills.

Table 2.
Means and standard deviations for situational interest subscales separate for each group and corellation in the total sample

Variable	Group 1 & 4		Group 2		Group 3		Correlations				
	Post-Test		Post-test		Post-test		1	2	3	4	5
	M	SD	M	SD	M	SD					
1. Novelty	3.18	1.43	2.20[a]	1.37	2.18[a]	1.32	.37*	.23	.24*	.25*	.32*
2. Challenge	1.83	1.04	1.78	1.03	1.73	.90	-.01	-.04	.12	.00	-
3. Attention demand	4.12	0.84	4.04	1.04	4.02	.89	.56*	.58*	.53*	-	
4. Exploration intention	3.54	1.01	3.65	1.06	3.52	.90	.64*	.68*	-		
5. Instant enjoyment	3.85	0.94	4.10	.91	3.92	.97	.82	-			
6. Total interest	3.96	1.00	3.78	1.06	3.78	.85	-				

note: a Significant variations in comparison to Group 1 and 4, Group 1 and 4: cognitively challenging physical activity with nonlinear games; Group 2: soccer skills; Group 3: track and field skills.

Table 3.
Resarch Variable

Variable
1. Novelty
2. Challenge
3. Attention demand
4. Exploration intention
5. Instant enjoyment
6. Total interest

In test condition 2, significant improvements from pre- to post-test were found for Group 1, $t(39) = -12.23$, $p < 0.001$, $d=1.51$, Group 2, $t(31) = -3.01$, $p=0.005$, $d=0.41$, but not for Group 3, $t(35) = -0.66$, $p=0.386$, and Group 4, $t(36) = -1.34$, $p=0.235$. In test condition 3, a significant improvement from pre- to post-test was found for Group 1, $t(39) = -11.45$, $p < 0.001$, $d=1.46$, but not for Group 2, $t(31) = -1.87$, $p=0.072$, Group 3, $t(35) = 1.24$, $p=0.224$, and Group 4, $t(36) = -1.49$, $p=0.145$. Regarding students' total score in the design fluency test, the 4 (Group) × 2 (Time) repeated measures ANOVA showed a significant interaction, $F(3, 140)=50.58$, $p < 0.001$, $\eta 2=.512$. Follow-up comparisons showed significant improvements from pre- to post-test for Group 1, $t(39) = -19.75$, $p < 0.001$, $d=1.82$, Group 2, $t(31) = -3.14$, $p=0.005$, $d=0.48$, but not for Group 3, $t(35) = -0.98$, $p=0.325$, and Group 4, $t(36) = -0.68$, $p=0.523$.

Intervention effects on the executive function of students in the waiting-list control group

To determine if the waiting-list control group (i.e. Group 4) students' scores on the three conditions of the design fluency test improved after the implementation of the experimental session, a repeated measures MANOVA was undertaken, revealing a significant multivariable improvement over time, $F(6, 124)=11.53$, $p < 0.001$, $\eta 2=.354$. Univariate testing demonstrated a significant improvement in test condition over time 1, $F(2, 64)=27.59$, $p < 0.001$, $\eta 2=.465$, test condition 2, $F(2, 64)=8.61$, $p < 0.001$, $\eta 2=.216$, and test condition 3, $F(2, 64)=17.55$, $p < 0.001$, $\eta 2=.342$. Pairwise comparisons with Bonferroni adjustment revealed that between time 2 and time 3, the results of Group 4 students in Test Condition 1 improved significantly ($p < 0.001$, $d=1.01$) and the difference between time 1 and time 3 was also significant ($p < 0.001$, $d=1.41$). In test condition 2, Group 4 students' scores improved significantly between time 2 and time 3 ($p=0.20$, $d=0. 45$) and the difference between time 1 and time 3 was also significant ($p < 0.001$, $d=0.71$). In test condition 3, roup 4 students' scores improved significantly between time 2 and time 3 ($p < 0.001$, $d=1.01$) and the difference between time 1 and time 3 was also significant ($p < 0.001$, $d=0.85$). The one-way ANOVA revealed that the total score on the test of design fluency increased significantly over time, $F (2, 31)=32.10$, $p < 0.001$, $\eta 2=.654$. Pairwise comparisons with Bonferroni adjustment revealed that the total score on the test of design fluency for Group 4 students increased considerably between time 2 and time 3 ($p < 0.001$, $d=0.96$) and the difference between time 1 and time 3 was also significant ($p < 0.001$, $d=1.31$).

Intervention effects on situational interest

To determine the effects of the intervention on the situational interest of students, a one-way MANOVA was conducted with group as the independent variable and the six subscale scores of the situational interest scale as the dependent variables. Results revealed a statistically significant multivariate impact, $F(12, 274)=2.11$, $p=0.016$, $\eta 2=.085$, on students' scores in the six subscales of the situational interest questionnaire. Univariate tests showed significant differences between groups in novelty, $F(2, 141)=9.73$, $p < 0.001$, $\eta 2=.121$. Bonferroni-

adjusted pairwise comparisons revealed that Group 1 and 4 students scored higher on novelty than Group 2 students ($p < 0.001$, $d=0.68$) and Group 3 ($p=0.004$, $d=0.78$) students

Discussion

This study investigated the impact of cognitively demanding physical activity with nonlinear pedagogical games on the executive functions and situational interest of students. The results demonstrated that these games enhanced the executive functions of students. These effects were greater than those of soccer or track and field abilities. Additionally, some evidence about the effects of these types of games on situational interest dimensions was given.

Students who participated in the experimental session with cognitively difficult physical activity and nonlinear pedagogical games significantly improved their scores on the design fluency test in all conditions and overall. Compared to kids who trained soccer or track and field skills and the control group pupils who were not involved in physical education throughout the first phase of the study, these improvements were greater. In the second phase of the study, when the control group students on the waiting list received the experimental session with cognitively difficult physical activity and nonlinear pedagogical games, these positive benefits on students' executive functions were repeated. Recent data suggests that the three types of cognitively taxing physical activity with nonlinear pedagogy games were equally successful in increasing students' executive functions, which these results support (Chow et al., 2007; Chow & Atencio, 2014).

This study suggests that a combination of these three game types can also be utilized effectively in physical education. The results of the present study are consistent with evidence from prior long-term interventions indicating that physical education programs that included cognitively demanding tasks were successful in increasing students' executive functions (Crova et al., 2014). In addition to enhancing earlier findings, the present study revealed that even a single physical education session with cognitively challenging physical activity and nonlinear pedagogic games can positively stimulate the executive functions of children (Gil Arias et al., 2014; Kaloka et al., 2023). In similarly, recent research including a single session of strength exercise (Tsuk et al., 2019), aerobic exercises, or aerobic dance has likewise revealed positive immediate effects on students' executive functioning (Kolovelonis et al., 2023). In addition, a growing body of research supports the positive acute benefits of single bouts of physical activity on students' cognition, including their executive abilities. The majority of these studies, however, focused on the acute effects of physical activity on inhibitory control, whereas the findings on other elements of executive functions (such as working memory and cognitive flexibility) were unclear and inconsistent. Cognitively difficult physical activity using nonlinear pedagogical games was found to have positive benefits on students' inhibitory control and cognitive flexibility.

The cognitively challenging physical activity with nonlinear pedagogy games can create optimal conditions for enhancing students' executive functions (Invernizzi et al., 2022). Indeed, these nonlinear pedagogy games such as, hop, pop, and tag, modified crazy traffic lights, and maps involve students in unpredictable, changing, and cognitively complex conditions (Atencio et al., 2014), requiring mental effort rather than simply moving in the playing area. Thus, when playing these games students are cognitively engaged and physically active. Furthermore, cognitively challenging physical activity with nonlinear pedagogy games can be considered an appropriate means for promoting the new tendency of designing and implementing physical activity and physical education programs that are physically and cognitively beneficial for students (Renshaw et al., 2010). Indeed, the results of this study supported this new approach of shifting from simply moving to moving with thought, suggesting that physical activities and motor and sport tasks should promote students' health-related outcomes and involve them in cognitively demanding conditions triggering their cognitive functions.

Students who practiced soccer skills, but not those who practiced track and field skills, showed some improvement in executive functions, which is an intriguing finding from this study. Students that participated in cognitively challenging physical activity with nonlinear pedagogical games had greater gains. In spite of this, the results imply that the qualities of the activities are crucial when pursuing effects on the executive functions of pupils. In fact, a recent study suggests that training open skills may have a higher impact on students' cognitive performance than practicing closed abilities (Formenti et al., 2021). The present study's findings supported this evidence. The development of executive functions may be facilitated by practicing soccer skills demanding coordination, balance, concentration, and problem solving (Diamond & Ling, 2016). Kids who participated in a six-month football program had enhanced coordination and executive functions compared to students who did not get physical education. The track and field skills, on the other hand, involved repetitive exercises with a low level of cognitive involvement, and hence did not significantly impact pupils' executive functioning. In fact, it has been reported that resistance-training and aerobic-exercise programs (such as jogging or walking) with lesser cognitive or motor-skill tasks have the least positive effect on executive functioning. Furthermore, elite athletes in open-skill sports had greater executive functions than those in closed-skill sports. In order to improve students' executive functions in physical education, it is necessary to select and implement relevant curriculum. Cognitively challenging physical activity games with nonlinear pedagogy fall into this category and can be utilized to engage students in physical activity while stimulating their executive processes. Importantly, practice in motor and sport skills can be modified to increase the cognitive difficulty for kids

(Tomporowski et al., 2015). Students who encounter shifting task conditions during practice may be able to transmit their knowledge more successfully, and the development of executive functions may be connected with self-regulated learning. Consequently, stimulating students' executive processes with suitably structured assignments and exercises may help improve their physical education learning. The creation of successful treatments for increasing students' executive functions and self-regulated learning in physical education will be aided by empirical proof of these correlations.

Conclusion

The results showed significant differences between groups only in the subscale of novelty. Specifically, the students who got the intervention consisting of cognitively challenging physical activity games (Groups 1 and 4) reported greater novelty scores than those who performed soccer or track and field abilities. It appears that these students viewed the games as novel, recognizing their unique qualities. This is a significant finding given that novelty satisfaction was a major predictor of intrinsic motivation in physical education and the absence of novelty in exercise routines may be related with low levels of physical activity engagement. Regarding the remaining variables of situational interest, no group differences were observed. The majority of students scored highly on the total interest and quick enjoyment scales. The fact that primary school pupils are strongly motivated to participate in physical education and enjoy team sports such as soccer and track and field activities such as running may help explain these findings. This potent motivational effect of physical activity was backed by studies demonstrating that incorporating physical activity into academic lessons increased students' engagement and enjoyment. All of these interpretations should be examined further in future research.

Students' physical activity levels and performance in soccer and track and field were not measured, which was a disadvantage of this study. Future research should address this limitation by examining the effects of cognitively demanding physical activity with nonlinear pedagogy games on students' physical activity levels and determining whether variations in these levels may result in differential effects on students' executive functions. However, additional study is required to expand our understanding of the physical activity aspects (e.g., intensity, duration, and type) that maximize the cognitive development benefits for students. In addition, components of motor and sport performance should be assessed to determine whether gains in executive functions are connected with higher levels of physical activity or motor and sport performance. Future research should explore the time-extended impact of long-term interventions with cognitively challenging physical activity with nonlinear pedagogic games on students' executive functions, given that this study covered a single session. Future research should investigate the efficacy of applying mental engagement principles to the acquisition of sport skills. Physical education programs may rely heavily on the utilization of effective teaching strategies to generate stimulating learning environments that foster mental engagement and the desire to acquire and master new abilities. Future research may also investigate other elements, such as actual and perceived skill in physical education, that may possibly mitigate the effect of cognitively demanding nonlinear pedagogical games on students' executive functions. In light of some concerns regarding the psychometric features of the design fluency exam, future research utilizing various tests evaluating executive functions should replicate the results of this study. This research will expand our understanding of the efficacy of cognitively enriched physical education interventions.

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Conflict of interest

No potential conflict of interest was reported by the authors

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