Article

Executive Functions, Motor Development and Digital Games Apply to School Children: A Systematic Mapping Study

Victória Branca Moron [1*], Débora Nice Ferrari Barbosa [1], Gustavo Roese Sanfelice [1], Jorge Luis Victória Barbosa [2], Daiana Rosso Ferreira Leithardt [3] and Valderi Reis Quietinho Leithardt [4]

[1] Cultural Diversity and Social Inclusion Graduate Program, Feevale University,ERS-239, 2755, Novo Hamburgo, RS, 93525-075, Brazil, vbmoron@feevale.br (V.B.M.), deboranice@feevale.br (D.N.F.B.), sanfeliceg@feevale.br (G.R.S.)
[2] Applied Computing Graduate Program, University of Vale do Rio dos Sinos, Av. Unisinos 950, Bairro Cristo Rei, São Leopoldo, RS, 93022-750, Brazil. jbarbosa@unisinos.br (J.L.V.B)
[3]Departamento de Química, Faculdade de Ciências, Universidade da Beira Interior, R. Marquês d'Ávila e Bolama, 6201-001 Covilhã, Portugal. daiana.leithardt@ubi.pt (D.R.F.L)
[4] COPELABS, Universidade Lusófona de Humanidades e Tecnologias,1749-024 Lisboa, Portugal. (V.R.Q.L)[5] VALORIZA, Research Center for Endogenous Resources Valorization, Instituto Politécnico de Portalegre, 7300-555 Portalegre, Portugal. valderi@ipportalegre.pt

* Correspondence: vbmoron@feevale.br

Abstract: Studies show that executive functions and motor development are associated among each other and with learning ability. A more technological lifestyle, related with digital culture, should be considered an important component to stimulate children. In addition, digital games constitute an element of the digital culture in which children are inserted. The aim of this study is to present a systematic mapping of the literature involving executive functions, motor development and the use of digital games in intervention programs for elementary school children, from 6 to 11 years old. Four databases were searched: PubMed, Scielo, Science Direct and SCOPUS, including publications between 2012 and March 2021. The initial results indicated 4881 works. After the selection process, 15 investigations that presented the central theme of the study were selected. The main results indicate that intervention strategies are quite heterogeneous. Most of the studies demonstrated significant positive effects after intervention protocols and were conducted in Europe and 46% of the studies were conducted in a school environment. No researches were identified that involved technological solutions involving executive functions, motor development and digital games in an integrated manner, constituting a field of future scientific research.

Keywords: executive function; digital games; motor skills; children.

1. Introduction

Many studies have investigated the association between motor and cognitive development, especially executive functions [1]. The development of motor skills enables children to perform goal-oriented movements and behaviors [2]. Motor skills require the involvement of cognitive operations such as perception, sequencing and monitoring [3]. Executive functions, in turn, control and regulate behavior in order to achieve specific goals. They are essential for the child to have more autonomy, emotional independence and action planning [4].

Executive functions are divided into several components. According to Diamond [5] the basic ones are: working memory, cognitive flexibility and inhibitory control. Components of a higher order stem from those: working memory (decision making, problem solving, selective attention, perceptual speed, anticipation and prediction); cognitive flexibility (planning and sequencing, spatial orientation, capacity for abstraction, problems and decomposition) and inhibitory control (selective attention, sustained attention, capacity to inhibit, resistance to interference and classifying).

The relationship between motor skills and executive functions is often explained by overlapping in brain areas important to both. Neural networks, including the frontal, parietal and motor cortex, are not only involved in underlying executive functions, but are also in motor tasks. In addition, the cerebellum and basal ganglia, crucial for motor skills, are also involved in executive functions [6].

At the behavioral level, the connection between motor skills and cognitive functions is explained by the involvement of executive functions in motor tasks [7]. Complex physical activities and sports that improve motor skills require focused attention, inhibitory control, and complex sequence memory. Consecutively, the development of executive functions is stimulated [8].

A child with proper motor development and cognitive tends to become a young and adult who learns better and has a better quality of life. This means that, by conquering good motor control and executive functions development, the child will be building the basics for their intellectual development, preventing them from having an impairment of motor and cognitive abilities. The stimulation of motor and cognitive development involves biological and maturational factors. This process varies according to the speed of progression among children, even though the motor development sequence is the same for everyone. A more technological lifestyle, associated with digital culture, should be considered a viable alternative to stimulate development in children development. Indeed, technology in contemporary society is a reference in the dimension of leisure, work and knowledge [9]. Today we need to deal with technologies and understand that development processes are involved in different contexts. Digital games represent a technological element that is part of the digital culture in which children are inserted.

The use of digital games allows for cognitive stimulation in a playful and natural context for children, considering an ecological approach. This considers the daily tasks that the individual practices or the context and environment in which they are inserted. In this context, there is a tendency to integrate ecological theories into several applications in neuropsychological science [10] and evaluation of motor development in children [11]. In the area of motor development, it is possible to combine bodily activities with activities from digital games. In this context, there is a cognitive theory in which the intellectual understanding of concepts is reinforced by bodily interactions with the physical world. This theory suggests that "embedded interactions" can stimulate the development of students' cognitive processes. In addition, it helps to understand abstract theoretical concepts through experience, exploration and practice of controlled body movements [12].

Studies have strived to understand and propose interventions that assess and/or promote motor and executive development [13]. Still, research involves interventions for the stimulation of executive functions mediated by technologies [14]. These interventions can take place in different contexts and involve different methodologies. Nevertheless, the school context is configured as an important environment, as it is part of the child's daily life, allowing interventions in an ecological approach. This approach assesses the child in a more global and natural way, considering their time and space and not just within specific conditions [15].

Considering the presented context, this paper investigates recent studies related to executive function and motor development through digital games. The study has two main proposes: 1) to evaluate the methodologies employed and, 2) to verify their strategies to conduct the intervention program considering school interventions. This research presents the results of a systematic literature mapping that analyzes studies involving executive functions, motor development and the use of digital games in intervention programs for elementary school children, from 6 to 11 years old.

This paper is organized as follows: section Method demonstrates the methodology used and state the questions pertinent to the systematic mapping of literature proposed here. Section Results and Discussion presents the results of the search in the databases, the findings on issues previously raised. Finally, section Conclusion addresses the main findings of the study.

2. Methods

This study is based on the methodological process for systematic mapping proposed by Peterson et al. [16], consisting of four distinct steps: 1) Definition of research questions; 2) Delimitation of the search process; 3) Definition of criteria for filtering results and 4) Classification of results for further analysis.

2.1 Research Questions

The research process was based on three groups of questions: General Questions (GQ), Focal Questions (FQ), and Statistical Questions (SQ), which were categorized as per Table 1.

Table 1. Research questions.

ID	Questions
GQ1	Which strategies were used to conduct the intervention program?
GQ2	What were the results of intervention programs that involved executive functions and motor development?
GQ3	What were the results of the intervention programs that involved executive functions and digital games?
GQ4	What were the results of the intervention programs that involved motor development and digital games?
FQ1	Which tests were used to assess executive functions?
FQ2	Which tests were used to assess motor development?
FQ3	How and which digital games were used? Statistical questions
SQ1	How many and which tasks involved application in a school environment?
SQ2	What is the distribution of articles by continent?
SQ3	What are the perceived trends?

2.2 Search Process

The process used to define the search strings was based on the use of specific keywords. As no studies were found involving the terms: executive functions, motor development and digital games, it was necessary to expand and segment the search in groups: executive functions and motor development, executive functions and digital games and motor development and digital games. This process originated the following search strings:

- ("executive function" OR "cognition") AND ("motor development" OR "motor skill") AND ("children" OR "childhood")

- ("executive function" OR "cognition") AND ("video game" OR "digital game" OR "digital technology" OR "software" OR "mobile device" OR "computer") AND ("children" OR "childhood")

- ("motor development" OR "motor skill") AND ("video game" OR "digital game" OR "digital technology" OR "software" OR "mobile device") AND ("children" OR "childhood").

The search strings were applied to 4 databases: PubMed[1], Scielo[2], Science Direct[3] e SCOPUS[4]; and included researches published between 2012 and 2021. Among those, PubMed is known for a being a literature database in the health area. The other databases were inserted in the search as

[1] https://pubmed.ncbi.nlm.nih.gov/
[2] https://scielo.org/
[3] https://www.sciencedirect.com/
[4] https://www.scopus.com/home.uri

they encompass a wide variety of periodicals in other areas. Mapped articles were stored using the tool Rayyan[5]. Subsequently, they were exported for bibliometric analysis at VOSViwer[6].

2.3 Filter of Results and Data Extraction

The following Inclusion Criteria (IC) were defined to filter the search results:

(IC1) – Articles published from 2012 to March 2021;

(IC2) – Publications in conferences, journal or workshop;

(IC3) – Complete and full access to content; and

(IC4) – Publication which involve children in typical development from Elementary School, from 6 to 11 years old.

Besides, the following Exclusion Criteria (EC) were defined for the second round of filtering:

(EC1) – Duplicated articles;

(EC2) – Theses, dissertations, books and reviews; and

(EC3) – Articles unrelated to the theme.

Figure 1 represents the search process. The adopted search process utilized the defined string on the databases publications for title, abstract, and keywords. Consequently, singular and plural of the keywords were used in the search string for each database, producing the initial results. Afterwards, filters EC1, EC2 and EC3 were applied. Subsequently, Keshav's [17] three-step technique was adopted: 1) reading the title, abstract and introduction, going through titles of sections and subsections, mathematical elements (if any) and conclusions. During this first step, the other exclusion criteria (EC3, EC4, and EC5) were added, since they were adherent to this part of the process, given the reading of all sections and subsections of the works. After the first step the other two were carried out: 2) analysis of figures, diagrams or illustrations; and 3) the reading o The initial databases search found a total of 44010 publications. From these, pre-selection included 52 publications for being in the thematic area, among which the final selection encompassed fifteen.

[5] https://www.rayyan.ai/

[6] https://www.vosviewer.com/

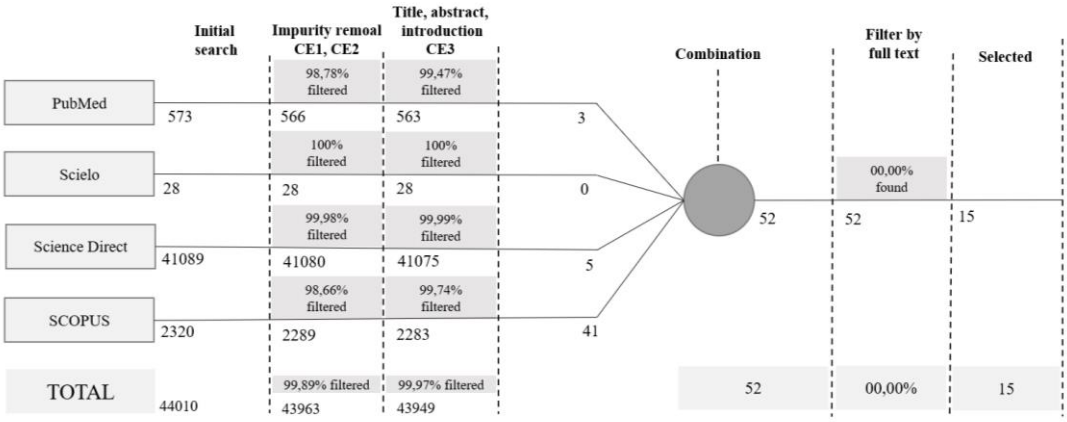

Figure 1: Steps in the search process.

3. Results and discussion

Table 2 presents the articles organized by authors and year of publication, title, sample (N), age, database, H-index, country, research duration and research focus. The results for each research question are presented below.

Table 2. List of mapped articles.

Authors (year)	Title	N	Age	Database	H-index	Country	Duration	Research
Alesi et al., (2014) [18]	Motor and cognitive development: The role of karate	39	9 years old	PubMed	32	Italy	2 weeks	FE+DM
Wunsch et al., (2016) [19]	No interrelation of motor planning and executive functions across young ages	217	3-10 years old	SCOPUS	95	Germany	1 session	FE+DM
Egger et al., (2018) [20]	The effect of acute cognitively engaging physical activity breaks on children's executive functions: Too much of a good thing?	216	7-9 years old	Science direct	93	Switzerlan d	1 session	FE+DM
Haapala et al., (2019) [21]	Longitudinal associations of fitness, motor competence, and adiposity with cognition	371	6-9 years old	SCOPUS	216	Finland	2 years	FE+DM
Ludyga et al., (2019) [22]	A Randomized Controlled Trial on the Effects of Aerobic and Coordinative Training on Neural Correlates of Inhibitory Control in Children	45	9-10 years old	PubMed	99	Germany	10 weeks	FE+DM
Van Der Fels et al., (2019) [23]	Relations between gross motor ski lls and executive functions, controlling for the role of information processing and lapses of attention in 8-10 year old children	732	8- 10 years old	SCOPUS	300	The Netherlan ds	2 weeks	FE+DM
Lin et al., (2021) [24]	Up-regulation of proactive control is associated with beneficial effects of a childhood gymnastics program on response preparation and working memory	48	7-10 years old	Science direct	122	Taiwan	8 weeks	FE+DM

Rudd et al. (2021) [25]	Comparing the efficacy (RCT) of learning a dance choreography and practicing creative dance on improving executive functions and motor competence in 6–7 years old children	62	6-7 years old	Science Direct	97	Australia	8 weeks	FE+DM
Mondéjar et al., (2016) [26]	Correlation between videogame mechanics and executive functions through EEG analysis.	12	8-12 years old	PubMed	91	Spain	1 session	FE+JD
Sánchez-Pérez et al., (2018) [27]	Computer-based training in math and working memory improves cognitive skills and academic achievement in primary school children: Behavioral results	104	7-10 years old	SCOPUS	95	Spain	13 weeks	FE+JD
Özçetin et al., (2019) [28]	The relationships between video game experience and cognitive abilities in adolescents	52	10-16 years old	SCOPUS	62	Turkey	1 year (min.)	FE+JD
Song et al., (2020) [29]	Validation of a mobile game-based assessment of cognitive control among children and Adolescents	100	9-16 years old	SCOPUS	300	South Korea	Not given	FE+JD
Sheeran et al., (2013) [30]	The effects of a daily, 6-week exergaming curriculum on balance in fourth grade children	64	4ª grade students	Science direct	30	Canada	8 weeks	DM+JD
Barnett et al., (2015) [31]	Playing Active Video Games may not develop movement skills: An intervention trial	95	4-8 years old	Science direct	24	Australia	6 weeks	DM+JD
McGlashanN et al., (2017) [32]	Improvement in children's fine motor skills following a computerized typing intervention	28	8-10 years old	Science direct	86	United Kingdom	4 weeks	DM+JD

During the analysis, special attention was given to mapping possible relationships between articles involving executive functions, motor development and digital games, since the search string was fragmented.

3.1 GQ1 - Which strategies were used to conduct the intervention program?

In this question, the general design of the studies was analyzed. The aspects of executive functions, motor development and digital games were presented, in pairs and in general. The type of analysis, the period and/or duration of the interventions, the application of tests, the type and number of experimental groups and control, if applicable, were identified.

One study (6%) used a non-randomized controlled design[24], and three (20%) used a randomized controlled design [22, 23, 25]. Three (20%) were experimental [18, 19, 20]; two longitudinal (14%) [21, 27], one (6%) performed the cross-sectional design [27] and five (33%) studies did not disclose which design was used [26, 30, 31, 32].

3.1.1 Executive functions and motor development

The study by Alesi et al. [18] compared motor skills (sprint, coordination and explosive leg strength) and basic executive functions in children. Participants were divided into two groups, a karate practitioners group and a sedentary group. Skills were measured by motor and cognitive tests. Anthropometric and motor measurements were performed in one session and cognitive assessments in another. The second session lasted 2 weeks.

Regarding the development of motor planning and executive functioning in children, the research by Wunsch et al. [19] evaluated participants who were tested using three motor tasks and three cognitive tasks. Children were separated into 1-year age groups. Participants were individually tested by the examiner. The session lasted on average between 90 and 100 minutes.

Also considering the coordination and aerobic capacity, the study by Egger et al. [20] compared the separate and/or combined acute effects of physical exertion and cognitive involvement induced by physical activity in the classroom, in children's executive functions. The study was conducted in one intervention session. Participants were randomly divided into intervention groups: combo group (high cognitive involvement and high physical effort); cognition group (cognitive involvement and low physical effort); aerobic group (low cognitive involvement and high physical effort) and control group (low cognitive involvement and low physical effort). Executive functions were measured before and immediately after a 20-minute intervention. To test the successful manipulation of cognitive engagement and physical exertion, heart rate, perceived exertion, and perceived cognitive engagement were assessed. Information on academic performance, aerobic fitness, and gross motor skills were collected independently 2–4 weeks after the intervention.

The research by Haapala et al. [21] investigated the longitudinal associations of cardiorespiratory fitness, motor competence and body fat percentage with cognition in children. Over two years, the maximum cycle ergometer test, motor competence tests, fat percentage measurement and cognitive assessment tests were performed.

As for coordination ability, the study by Ludyga et al. [22] compared the effects of aerobic and coordinative training on behavioral and neurophysiological measures considering inhibitory control. This study was conducted through groups that performed aerobic training, coordination training, or assisted homework sessions for 10 weeks. Inhibitory control and aerobic and coordinative capacity were evaluated using specific tests. During the data collection period, outcome evaluators were blinded to the group allocation of participants. In the intervention period, the number of physical education classes was identical between groups (3 × 45 min per week). In addition, both intervention groups completed a training program. The program consisted of three 45-minute sessions per week, during leisure time (after school). An instructor with experience in aerobics and coordination training with children supervised these sessions.

In the research by Van Der Fels et al. [23], the link between gross motor skills and aspects of executive functioning was investigated. Furthermore, the role of information processing and attention lapses in the relationship between motor skills and executive functions was analyzed. The children in this study were part of a project called "Learning in Motion". This project evaluated the effects of two physical activity interventions on physical and cognitive outcomes, academic performance, brain structure, and brain function. Gross motor skills were assessed during one or two physical education classes in circuit form. Executive functioning tasks were evaluated in a quiet room at the children's school. Children were individually tested by trained examiners. The tests were evaluated in two parts over two days.

The study by Lin et al. [24] focused on the effect of an 8-week physical activity program. Gymnastics activities were carried out. The activities were based on motor skills and variation in event-related brain potentials during a working memory task. The gymnastics group engaged in a gymnastics program. Children in the control group were asked to maintain their typical routine during the intervention period. The performance of working memory and motor skills were assessed by using specific tests.

In the research by Rudd et al. [25] the effect of two dance curricula on the executive functions and motor competence of elementary school children was examined. One was a dance curriculum that emphasized creativity and the other was based on choreographed dance with a high level of cognitive demand. The intervention lasted for an 8-week period, twice a week. Executive functions and motor competence were assessed at three moments (baseline, pre-intervention and post-intervention).

3.1.2 Executive Functions and Digital Games

In the studies by Mondéjar et al. [26], the activities of the brain's frontal lobe were analyzed. Analyzes took place during a psychological assessment and while the participants were playing. The experiment was divided into two stages, which were based on psychological assessments and videogame-based assessments. The analysis was performed by collecting brain signals during the two stages of the experiment. Signals were analyzed with a neuroheadset electroencephalogram.

Considering also school performance, the study by Sánchez-Pérez et al. [27] examined the effectiveness of computer-based school training. The training consisted of two components, working memory and math tasks. The study followed three phases, pre-training, training and post-training. The pretest lasted approximately 3 weeks and was followed by 13 weeks of training for the experimental group. One week after the end of the training period, children in both groups were reassessed. To assess the effects of training, executive functions, IQ, grades, and math and reading skills were measured. For this purpose, standardized tests, math and language scores were used.

The research by Özçetin et al. [28] evaluated the effect of commercial video games on the executive functions of children and adolescents. Volunteer participants were chosen after an IQ test and an initial interview. Those chosen regularly played video games for at least 1 hour a day, 5 days a week, for at least a year. The players had their executive functions evaluated through neuropsychological tests. Other data such as demographics, medical and video game types were collected through questionnaires.

The study by Song et al. [29] assessed cognitive control through a cell phone game and compared it with traditional neuropsychological test results. The analyzes observed relationships between the various gaming behavior scores, neuropsychological tests and a self-reported executive function difficulty questionnaire.

3.1.3 Motor Development and Digital Games

The research by Sheehan et al. [30] used a purpose-built exergame center in a school. The intent was to test fourth graders with an exergame curriculum designed to improve postural stability. The program was implemented over 6 weeks, 34 minutes a day, 4-5 days a week. Three groups were observed, one intervention and two control groups (1- physical education focused on agility, balance and improvement of coordination, 2 – typical curricular class of Physical Education). The assessments were carried out through a platform for balance tests.

Another study also used exergames. However, Barnett et al. [30] investigated the impact of active video games on children's real and perceived object control skills. Children in the intervention group played the exergame 6 hours a week for 6 weeks after school hours. Assessments were carried out for the object control competence and a valid pictorial instrument for the perceived object control competence.

Finally, the research by McGlashan et al. [32] explored whether an online interactive typing intervention could improve children's scores for manual dexterity. This study also implemented a serial touch reaction time task as an index of children's finger learning. The intent was to see if performance on this task would improve after the intervention. Children in the intervention group played at home for a period of 4 weeks. The control group did not play any games. Standardized tests were used to measure serial reaction time, motor and educational performance.

3.1.4 General Analysis

In regards to the executive functions of the twelve studies, eight analyzed them in general [18, 20, 21, 25, 26, 27, 28, 29], one study analyzed only the inhibitory control [22], another considered only the working memory [24], one the inhibitory control and working memory [23] and one did not specify [19].

Out of the eleven studies on motor development, two considered gross motor skills in general [23, 24,]; an object control ability [31]; a manual dexterity [31]; three considered the coordination [18, 20, 22] ; one the balance [29]; one the motor planning [19]; and two observed motor competence [21, 25].

The average time of application of interventions was 3.5 months. The shortest applications lasted 1 session, the longest 2 years and one study did not disclose the duration.

Nine studies (60%) performed pre and post-tests. One of the studies, as it has a longitudinal design, had tests performed over the 2 years of intervention [21].

Three studies (20%) recorded electroencephalographic (EEG) activity [22, 24, 26].

Six studies (40%) used an intervention group and a control group [18, 21, 24, 27, 31, 32]; one study (6%) used two intervention groups [25]; one study (6%) used two intervention groups and a control group [22]; one study (6%) used three intervention groups and a control group [20]; one study (6%) used eight intervention groups and an additional adult group [19] and one study (6%) used two control groups and an experimental group [30].

3.2 GQ2 - What were the results of intervention programs that involve executive functions and motor development?

Eight studies presented results related to executive functions and motor development. In the research by Alesi et al. [18], there were significant differences between children who practice karate and sedentary children. The karate practitioners had better speed times, explosive leg strength and coordination skills. Furthermore, they scored better on working memory and selective visual attention.

In Wunsch et al. [19], the older the children were, the better was their performance. Performance on separate tasks was not correlated among participants in different age groups. In addition, there was no association between performance on the motor and cognitive tasks used to control for age.

In the study by Egger et al. [20], the results demonstrated a significant negative effect for cognitive involvement in the executive function of cognitive flexibility. No effects were found on working memory or inhibitory control. No significant effects were found for physical effort or the interaction of physical effort and cognitive involvement. Thus, the results indicated that an acute session of cognitive involvement in physical activity in the classroom could deteriorate children's cognitive performance.

The results of Haapala et al. [21] demonstrated that higher motor competence at baseline predicts better cognition during the first 2 years of schooling in boys, but not in girls. Furthermore, cardiorespiratory fitness and adiposity were not associated with cognition in either sex.

In the research by Ludyga et al. [22], no significant differences were found. However, the results indicate that such training programs have no negative influence on the inhibitory aspect of executive functions. And aerobic and coordination training led to an improvement in cardiovascular fitness.

In the findings of Van Der Fels et al. [23], lapses of attention were related to all executive functions, while processing speed. After controlling for information processing and attention spans, gross motor skills were specifically related to visuospatial working memory and response inhibition. The results indicated that gross motor skills are related to aspects of executive functions that are more directly involved and share common underlying processes.

In the intervention of Lin et al. [24], the results showed significant improvements in motor skills and working memory between the pre and post-tests.

In the study by Rudd et al. [25] both dance groups promoted the development of inhibitory control and the working memory capacity presented signs of improvement. Motor competence did not improve beyond typical development. No significant differences were found between the groups either.

3.3 GQ2 What were the results of intervention programs involving executive functions and digital games?

The study by Mondéjar et al. [26] found a clearly prominent activity at the prefrontal level of the brain that is related to executive functions. Furthermore, it was observed that the link between cognitive abilities and certain video game mechanics is not disjointed, that is, one mechanic develops several cognitive abilities, and each skill can be developed by several mechanics. Thus, the authors established relationships between cognitive skills and the mechanics involved: general cognitive activation (precise action and logical puzzles); executive functions (learning patterns and logic puzzles); working memory (mime sequences, logic puzzles and timely action); cognitive flexibility (logical puzzles and timely action) and inhibitory control (mime sequences, precise action and pattern learning).

The research by Sánchez-Pérez et al. [27], showed a significant improvement in cognitive skills, such as non-verbal IQ and inhibition. It also demonstrated better academic performance in math and reading among children who participated in the training compared to those who did not. Most of the improvements were related to training in working memory tasks.

In the studies by Özçetin et al. [28], visual memory scores were slightly better in the game group. The study by Song et al. [29] demonstrated that gambling scores were significantly related to various cognitive control functions and differentiated between high and low cognitive control groups.

3.4 GQ3 - What were the results of intervention programs involving motor development and digital games?

The study by Sheehan et al. [30] demonstrated that the intervention group significantly improved postural stability over the 6 weeks compared to the control group in the typical Physical Education class. Improvements were also evidenced in the control group of the Physical Education class focused on agility, balance and coordination.

In the research by Barnett et al. [31] significant improvements were shown over time, but there was no significant difference in between the groups. The intervention did not alter perceived object control.

Based on the analyzes by McGlashan et al. [32], children in the intervention group significantly improved their manual dexterity scores compared to the control group.

3.5 FQ1 – Which tests were used to assess executive functions?

Several tests can be used that assess working memory, cognitive flexibility and inhibitory control. According to Diamond [5], these elements are considered basic components of Executive Functions.

For **working memory**, the study by Alesi et al. [18] used Visual Discrimination Test, Reaction Time Test, Forward and Backward Digit Test and Corsi Block-Tapping Test. Mondejar et al. [26] used a test adapted from the Trail Making Test (TMT); Egger et al. [20] the Backward Color Recall Task; Sánchez-Pérez et al. [27] the Digit range task, based on the subtest of the Wechsler Intelligence Scale for Children (WISC-III) and points task. Özçetin et al. [28] applied the Verbal Fluency Test (FAS Verbal Fluency), California Verbal Learning Test-Children's Version (CVLT-C) and Benton Visual Retention Test (BVRT); Van Der Fels et al. [23] the Digit Span Backward of the WISC-III Digit Span task, for the verbal working memory and, an adapted version of a Visuospatial Memory task, for the visuospatial working memory. Lin et al. [24] used the Modified Delayed Matching Test, which examines spatial working memory and Rudd et al. (2021) used list sorting working memory.

For **cognitive flexibility**, the research by Mondéjar et al. [26] used the Washers Test, an adaptation of the Tower of Hanoi (TOH). Egger et al. [20] chose the Flanker Task with a “mixed” block; and Rudd et al. [25] applied the dimensional change card sort (DCSS) test.

For **inhibitory control**, the study by Mondéjar et al. [26] used the Interference Test (an adaptation of the Stroop test); Egger et al. [20] the Eriksen Flanker Task adapted for children [20]; Sánchez-Pérez et al. [27] the go/no go task and the points task. Ludyga et al. [22] and Rudd et al. [25] used the Flanker Task; Özcetin et al. [28] the Stop Signal Task and original Stroop test. Van Der Fels et al. [23] applied a modified version of the Flanker Task, for the interference control and Stop Signal task and Song et al. [29] used a Korean Version of the Stroop Color-Word Test for Children and the Korean Version of the Color Trails Test (CTT).

Some researches applied tests that evaluated the **three basic executive functions** (cognitive flexibility, inhibitory control and working memory), such as Alessi et al. [18] who used the Tower of London; Sánchez-Pérez et al. [27] the Spanish version of the Kaufman Brief Intelligence Test (K-Bit); Haapala et al. [21] used the Raven's Colored Progressive Matrices for non-verbal reasoning; Özçetin et al. [28] the Trail Making Tests AB (TMT AB) and Song et al. [29] applied the Wechsler Scale of Korean Intelligence for Children - Fourth Edition (K-WISC-IV-C).

Other surveys **did not clearly specify** which executive components were evaluated, such as Wunsch et al. [19] who used the Tower of Hanoi task; the Mosaic Task, a subtest of the Wechsler Intelligence Scale and D2-Attention Resistance Test in Three Versions.

3.6 FQ2 – Which tests were used to assess motor development?

With regard to studies that evaluated gross motor development, Ludyga et al. [22] evaluated gross motor skill through the Heidelberg Gross-Motor Test (HGMT). Two studies used the Körper Koordinationstest für Kinder (KTK). Egger et al. [20] measured gross motor coordination and Van Der Fels et al. [23] used three KTK items and one item from the Bruininks-Oseretsky Motor Proficiency Test, 2nd Edition (BOT-2). Barnett et al. [31] assessed object control competence through the Gross Motor Development Test, 2nd Edition (TGMD-2). Two studies used the second edition of the Movement Assessment Battery for Children (MABC-2), however, Lin et al. [24] used it to evaluate gross motor skill and McGlashan et al. [32] to evaluate fine motor skill.

The study by Alessi et al. [18] assessed motor skills through a battery consisting of three tests: 20-meter Sprint Test, Agility and Standing board jump Test.

The research by Haalapa et al. [21] evaluated speed and agility through the 50m Suttle Run test, static balance through the Modified Flamingo Balance Test, and manual dexterity and movement speed of the upper limbs through the Box and Block Test. Sheehan et al. [30] also assessed balance through tests on the HUR BT4™ platform, for advanced postural stability tests.

Rudd et al. [25] assessed motor competence through the Canadian Agility and Movement Skill Assessment (CAMSA). This assessment consists of 7 tasks, which must be completed in sequence as quickly and accurately as possible.

In the study by Wunsch et al. [19] the anticipatory motor planning was evaluated. For that, a number of tests were used to measure the end-state comfort effect (ESC), considering three different tasks: bar transport task; sword rotation task and height grab task.

3.7 FQ3 - How and which digital games were used?

Out of the seven studies that used digital games, two used serious games[7]. The research by Mondéjar et al. [26] used a serious game set focused on specific action mechanics. These games were developed by several students of the Faculty of Computer Science of Ciudad Real (University of Castilla-La Mancha), namely: Dreamskeeper (move the mouse to avoid obstacles); KittenQuest (avoid obstacles in your way in a timely manner); CrazyFarm (show visual and sound sequences that need to be imitated); Api's Adventures (platform on which the particular pattern that enemies repeat must be identified to reach the next levels) and Kunoichi (plan a set of basic actions in terms of logical moves to exit the gate). The study by Song et al. [29] used CoCon, for mobile device. In this game, cognitive control skills are assessed simultaneously while users are playing. A total of ten games are included that assess sustained attention, working memory, inhibitory ability and response selection, and categorization. Tasks were sorted based on their difficulty levels.

Regarding Active Videogames, two used intervention with exergames for six weeks. The investigation by Sheehan et al. [30] used an exergame teaching station, set up on the stage of an elementary school. Respondents were divided into three subgroups that alternated to a different season each day, 4 to 5 times a week. The subgroup allowed equal rotation between three stations; iDance ™, XR Board ™/Lightspace ™ and Wii Fit ™ Plus. All students from the iDance ™ station started at the basic levels. However, by the third week they were able to select their own difficulty level to match their skill level. Lightspace ™ and XR Board ™ were combined into a single season due to the difficulty of virtual snowboarding. After two downhill races, a student switched to Lightspace ™ to give their legs a rest and play games that require arm activity. The investigation by Barnett et al. [31] used Nintendo Wii® sessions one hour a week after school hours. In this intervention, two consoles were provided, with four children allocated to each timeslot. Children played in pairs. Two research assistants supervised each session but were instructed not to provide skills training. Nintendo Wii® games have been specifically chosen to represent a variety of sports that require the use of object control skills. A different set of games was offered every fortnight and children could choose.

The study by Özçetin et al. [28] considered the games that respondents routinely played at home, at least 1 hour a day, 5 times a week. To this end, the researchers classified the games into five game categories: online role-playing games; online first-person shooter; real-time strategy games; action/adventure games and survival/platform games.

---

[7] Type of game focused on teaching specific content or for the development of behavioral or operational skills (CHASRKY, 2010).

The research by Sánchez-Pérez et al. [27] used 40-minute computerized training sessions instead of a specific game. Therefore, each child started inside a spaceship and there were four planets/satellites in front of them. Each planet/satellite represented a training task: Planet Fire represented the n-back task, Earth denoted math activities, Moon was the working memory range task, and Planet Ice represented the task in abstract ways. The tasks included in Planet Fire, Moon and Planet Ice formed working memory training, while activities on Earth conformed to mathematical training.

Finally, the study by McGlashan et al. [32] used a personalized computerized manual dexterity touch interactive online game. Children could choose between two games, Dace Mat Typing or Typing Chef. Participants were asked to play 5 times a week for about 10 minutes each time for 4 weeks. In the game, children pressed a series of four keys with four different fingers from their dominant hand (index, middle, ring and little fingers) on a keyboard. The task was divided into two conditions, random and sequential.

3.8 SQ1 - How many and which works were applied in a school environment?

Of the analyzed studies, seven (46%) were carried out in a school environment. Three studies were conducted during physical education classes [22, 23, 30]. However, the study by Ludyga et al. [22] also considered after school, in leisure time. Egger et al. [20] applied in the classroom and Sánchez-Pérez et al. [27] inside the computer lab. Barnett et al. [31] conducted the study in the school environment, but after school hours. And Rudd et al. [25] conducted the intervention during physical education classes but did not specify at what times.

3.9 SQ2 - What is the distribution of articles by continent?

To identify the countries where the works were developed, the institution of origin of the authors of the article, the place of application of the practical tests and direct references to the country in the text were considered.

It was possible to notice a varied distribution between different countries. Therefore, Figure 2 shows the distribution grouped by continents: nine publications were in Europe (Germany (2), Switzerland, Netherlands, Finland, Germany, Italy and Spain (2)), three publications were in Asia (Taiwan, South Korea and Turkey), two publications in Oceania (Australia (2)) and one publication in North America (Canada).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 29 October 2021

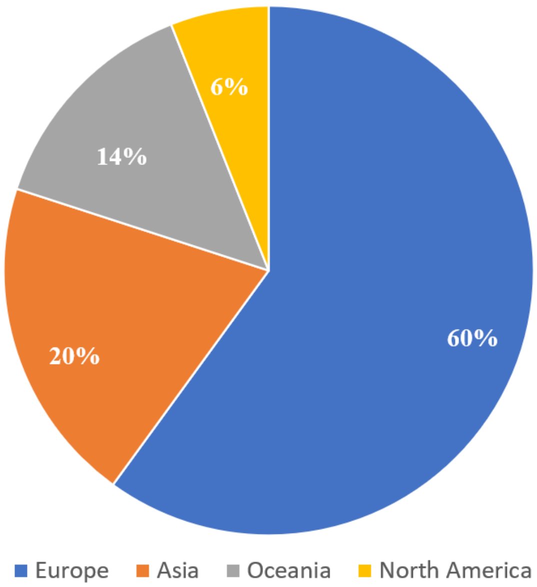

Figure 2: Participation of continents in the publications.

3.10 SQ3 – What are the perceived trends?

Figure 3 shows the frequency of publications on the subject, which began to be explored in 2013 and had its peak of scientific production in 2019.

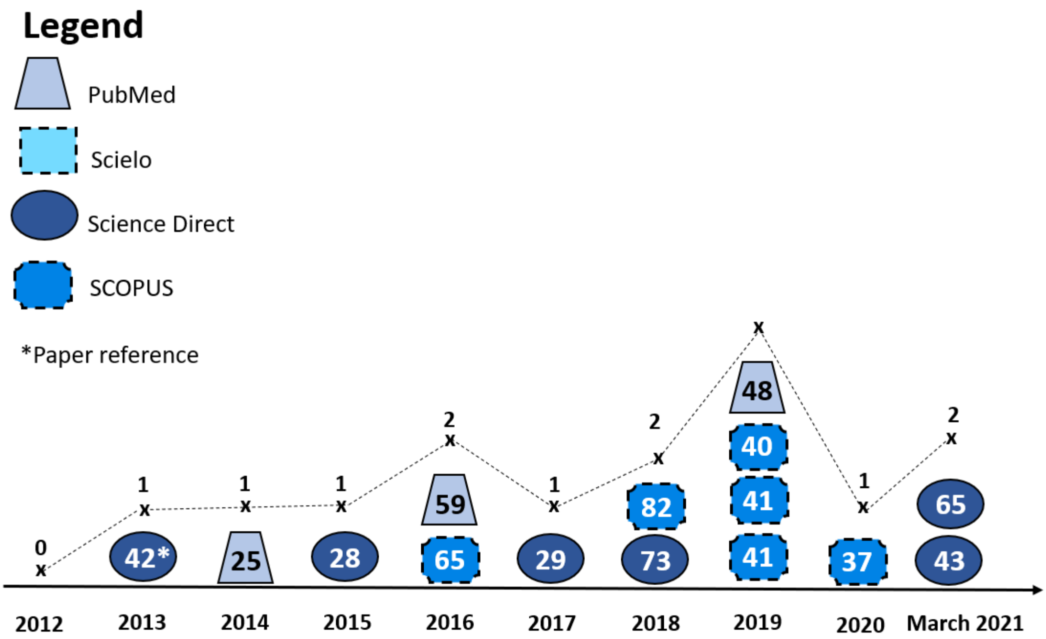

Figure 3. Frequency of publications and databases

The databases with most publications were Scopus and Science Direct, accounting for 80% of the total, validating the effectiveness of these databases. PubMed, despite being a reference database in the health area, accounted for 20% of the studies and Scielo had no articles identified in the process.

Trends in “terms” were identified through bibliometric mapping [33], performed with the VOSviewer tool. Figure 4 shows the density of terms and the formation of clusters of interest, grouped by colors according to the proximity of the terms. The identified clusters are presented and characterized below:

- Green: It houses the term “children”, the most prominent among all clusters, therefore, the term with the highest occurrence in all 15 articles.
- Light blue: just one term, related to cognitive.
- Purple: term on cognition that enters the yellow group.
- Yellow: Cluster centered on school-age children.
- Dark blue: involves executive functions and exercise.
- Red: Related to cognition and technology.

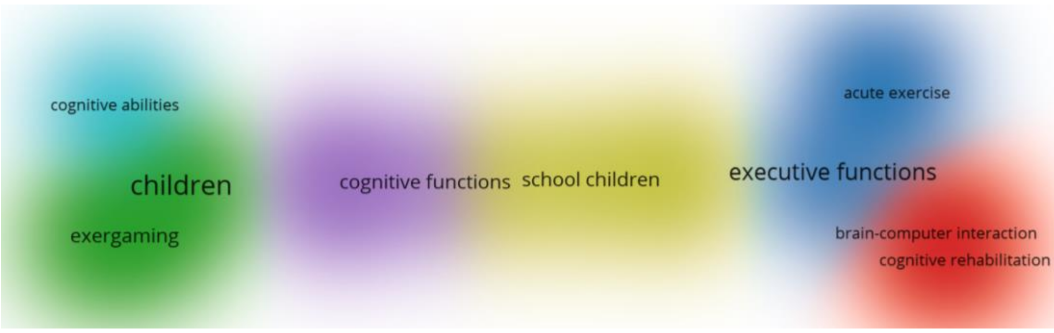

Figure 4: Cluster Density Map.

Figure 5 provides an overview of the connections between terms in the same or different clusters. The pairs and strength of connection of these relations are determined by factors such as occurrence of terms in all imported documents, and number of documents with the same database source or authorship [34]. This model represents the overlapping of chronological incidence of terms on the cluster map. The most recent term detected by the tool was “cognitive functions”, which within the same cluster is related to cardiorespiratory and motor exercises and obesity.

In addition, the global view shows the composition of the terms used in the search. Children and executive functions are somehow related to most terms. However, exercises and technology showed no links.

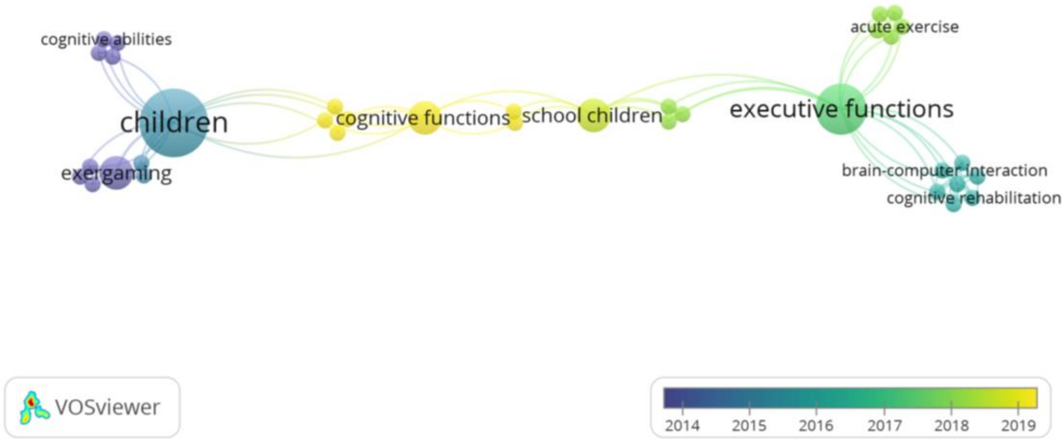

Figure 5 - Overview of the relationship among terms.

4. Conclusions

This work identified the current scenario in research involving interventions related to executive functions, motor development and digital games for children. The systematic mapping made it possible to identify and analyze the articles selected in this study. The selected articles refer mainly to interventions related to executive functions and motor development (54%).

The study identified a growing interest in the topic. Still, the studies are quite heterogeneous in relation to the duration of interventions, analyzed executive functions and motor skills, applied tests and games.

On the results, most studies showed significant positive effects with regard to interventions. Some point out that physically active children demonstrate better executive functioning when compared to sedentary children.

Furthermore, activities that involve some types of motor skills are more related to some executive functions. In particular, this element is noticed when they share common underlying processes, such as coordination activities, which are more related to working memory and inhibitory control.

Regarding executive functions and digital games, serious games and commercial videogames seem to stimulate cognitive processes. Research also shows that programs involving videogames that stimulate executive functions improve school performance.

In reference to the school environment, less than half of the studies (46%) developed their interventions in this context. Most of these studies found significantly positive results between pre and post intervention. These studies reinforce the importance and effectiveness of interventions with both digital games and executive functions and motor development, considering a school environment in an ecological approach. Since these interventions impact the development of children, their academic life and cognitive skills [4].

Considering the research field of this work, it is considered to have the following strengths: 1) initial evidence that works in the field of research using executive functions, motor development and digital games aimed at children with applications in ecological environments, specifically in the school context, are still incipient; and 2) there is also no research that takes into account executive functions, motor development and digital games simultaneously. Finally, this investigation identified a gap in the area neurocognitive, motor and digital games area to stimulate executive functions and motor development on children in the school context. As future work, these criteria should be united in a school neuropsychological and motor intervention using digital games, which should be carried out to discover their effects and effectiveness in this target group.

Finally, despite attempts to mitigate risks, certain choices may have affected the outcome of this systematic mapping. The choice of databases is a risk factor. To cover more results, four databases were selected. However, the results showed that certain databases were ineffective, such as Scielo. The search process, inclusion and exclusion criteria, in addition to the authors' own assessment of relevance also delimited the results, possibly excluding relevant articles. We sought to minimize these risks following the methodology of Keshav [17] and Petersen et al. [16].

Author Contribuition: Conceptualization, V.B.M.; D.N F.B. and G.R.S..; methodology, V.B.M., D.N.F.B., G.R.S., J.L.V.B; formal analysis, V. B. M.; D.N.F.B. and G.R.S.; investigation, V.B.M.; D.B., J. L.V.B., V.R.Q.L and G.R.S.; resources, V.B.M.; D.N.F.B. and G. R. S.; data curation, V.B.M.; writing—original draft preparation, V.B.M.; writing—review and editing, J. L.V.B.; D.N.F.B. D.R.F.L and V.R.Q.L; visualization, V.B.M.; D.N.F.B.; D.R.F.L and G.R.S.; supervision, D.N.F.B, G.R.S. J.L.V.B.; Financial, V.R.Q.L. and D.R.F.L All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by national funds through the Fundação para a Ciência e a Tecnologia, I.P. (Portuguese Foundation for Science and Technology) by the project UIDB/05064/2020 (VALORIZA – Research Centre for Endogenous Resource Valorization) and it was partially supported by Fundação para a Ciência e a Tecnologia under Project UIDB/04111/2020, and ILIND–Instituto Lusófono de Investigação e Desenvolvimento, under projects COFAC/ILIND/COPELABS/1/2020and COFAC/ILIND/COPELABS/3/2020**.**

Acknowledgments: The authors would like to thank the Feevale University (FEEVALE), the Applied Computing Graduate Program (PPGCA/UNISINOS), the Research Support Foundation of the State of Rio Grande do Sul (FAPERGS), the National Development Council Scientific and Technological (CNPq) - Brazil, and the Coordination for the Improvement of Higher Education Personnel - Brazil (CAPES) - Code Funding 001.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Geertsen, S. S.; Thomas, R.; Larsen, M. N.; Dahn, I. M.; Andersen, J. N.; Krause-Jensen, M.; Korup, V.; Nielsen, C. M.; Wienecke, J.; Ritz, C.; Krustrup, P.; Lundbye-Jensen, J. Motor Skills and Exercise Capacity Are Associated with Objective Measures of Cognitive Functions and Academic Performance in Preadolescent Children. *PLoS One* **2016**, *11* (8), 1–16.

https://doi.org/10.1371/journal.pone.0161960.
2. Jaakkola, T.; Yli-Piipari, S.; Huotari, P.; Watt, A.; Liukkonen, J. Fundamental Movement Skills and Physical Fitness as Predictors of Physical Activity: A 6-Year Follow-up Study. *Scand. J. Med. Sci. Sport.* **2016**, *26* (1), 74–81. https://doi.org/10.1111/sms.12407.
3. Roebers, C. M.; Kauer, M. Motor and Cognitive Control in a Normative Sample of 7-Year-Olds. *Dev. Sci.* **2009**, *12* (1), 175–181. https://doi.org/10.1111/j.1467-7687.2008.00755.x.
4. Schmidt, M.; Egger, F.; Benzing, V.; Jäger, K.; Conzelmann, A.; Roebers, C. M.; Pesce, C. Disentangling the Relationship between Children's Motor Ability, Executive Function and Academic Achievement. *PLoS One* **2017**, *12* (8). https://doi.org/10.1371/journal.pone.0182845.
5. Diamond, A. Executive Functions. *Annu. Rev. Psychol.* **2013**, *64*, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750.
6. Diamond, A. Close Interrelation of Motor Development and Cognitive Development and of the Cerebellum and Prefrontal Cortex. *Child Dev.* **2000**, *71* (1), 44–56. https://doi.org/10.1111/1467-8624.00117.
7. Livesey, D.; Keen, J.; Rouse, J.; White, F. The Relationship between Measures of Executive Function, Motor Performance and Externalising Behaviour in 5- and 6-Year-Old Children. *Hum. Mov. Sci.* **2006**, *25* (1), 50–64. https://doi.org/10.1016/j.humov.2005.10.008.
8. Diamond, A. Effects of Physical Exercise on Executive Functions: Going beyond Simply Moving to Moving with Thought. *Physiol. Behav.* **2015**, *176* (3), 139–148.
9. Paiva, N. M. N.; Costa, J. S. A Influência Da Tecnologia Na Infância : Desenvolvimento Ou Ameaça? *Psicologia.pt* **2015**, 1–13.
10. Zimmermann, N.; De Oliveira Cardoso, C.; Kochhann, R.; Jacobsen, G.; Fonseca, R. P. Contributions of the Ecological Approach to the Neuropsychology of Executive Functions. *Temas em Psicol.* **2014**, *22* (3), 639–654. https://doi.org/10.9788/TP2014.3-09.
11. Berlese, D.; Ferrari Barbosa, D. N.; Mossmann, J. B.; Theisen Schneider, G. T. S.; Benites, B. GameMove: A Proposal for Evaluation of Motor Development in Children Mediated by Digital Games. *Int. J. Innov. Educ. Res.* **2020**, *8* (1), 169–177. https://doi.org/10.31686/ijier.vol8.iss1.2148.
12. Johnson, K.; Pavleas, J.; Chang, J. Kinecting to Mathematics through Embodied Interactions. *Computer (Long. Beach. Calif).* **2013**, *46* (10), 101–104. https://doi.org/10.1109/MC.2013.363.
13. McClelland, M. M.; Cameron, C. E. Developing Together: The Role of Executive Function and Motor Skills in Children's Early Academic Lives. *Early Child. Res. Q.* **2019**, *46*, 142–151. https://doi.org/10.1016/j.ecresq.2018.03.014.
14. Mossmann, J. B. Um Exergame Para Estimulacao de Componentes Das Funcoes. **2016**, 369–376.
15. de Cardoso, C. O.; Zimmermann, N.; Paraná, C. B.; Gindri, G.; De Pereira, A. P. A.; Fonseca, R. P. Brazilian Adaptation of the Hotel Task A Tool for the Ecological Assessment of Executive Functions. *Dement. e Neuropsychol.* **2015**, *9* (2), 156–164. https://doi.org/10.1590/1980-57642015dn92000010.
16. Petersen, K.; Vakkalanka, S.; Kuzniarz, L. Guidelines for Conducting Systematic Mapping Studies in Software Engineering: An Update. *Inf. Softw. Technol.* **2015**, *64*, 1–18. https://doi.org/10.1016/j.infsof.2015.03.007.
17. S. Keshav. How to Read a Paper. *Key Top. Surg. Res. Methodol.* **2007**, *37* (3), 545–555. https://doi.org/10.1007/978-3-540-71915-1_40.
18. Alesi, M.; Bianco, A.; Padulo, J.; Vella, F. P.; Petrucci, M.; Paoli, A.; Palma, A.; Pepi, A. Motor and Cognitive Development: The Role of Karate. *Muscles. Ligaments Tendons J.* **2014**, *4* (2), 114–120. https://doi.org/10.11138/mltj/2014.4.2.114.
19. Wunsch, K.; Pfister, R.; Henning, A.; Aschersleben, G.; Weigelt, M. No Interrelation of Motor Planning and Executive Functions across Young Ages. *Front. Psychol.* **2016**, *7* (JUL), 1–16. https://doi.org/10.3389/fpsyg.2016.01031.
20. Egger, F.; Conzelmann, A.; Schmidt, M. The Effect of Acute Cognitively Engaging Physical Activity Breaks on Children's Executive Functions: Too Much of a Good Thing? *Psychol. Sport Exerc.* **2018**, *36* (March), 178–186.

https://doi.org/10.1016/j.psychsport.2018.02.014.

21. Haapala, E. A.; Lintu, N.; Väistö, J.; Tompuri, T.; Soininen, S.; Viitasalo, A.; Eloranta, A. M.; Venäläinen, T.; Sääkslahti, A.; Laitinen, T.; Lakka, T. A. Longitudinal Associations of Fitness, Motor Competence, and Adiposity with Cognition. *Med. Sci. Sports Exerc.* **2019**, *51* (3), 465–471. https://doi.org/10.1249/MSS.0000000000001826.
22. Ludyga, S.; Koutsandréou, F.; Reuter, E. M.; Voelcker-Rehage, C.; Budde, H. A Randomized Controlled Trial on the Effects of Aerobic and Coordinative Training on Neural Correlates of Inhibitory Control in Children. *J. Clin. Med.* **2019**, *8* (2), 1–12. https://doi.org/10.3390/jcm8020184.
23. van der Fels, I. M. J.; te Wierike, S. C. M.; Hartman, E.; Elferink-Gemser, M. T.; Smith, J.; Visscher, C. The Relationship between Motor Skills and Cognitive Skills in 4-16 Year Old Typically Developing Children: A Systematic Review. *J. Sci. Med. Sport* **2015**, *18* (6), 697–703. https://doi.org/10.1016/j.jsams.2014.09.007.
24. Lin, C. C.; Hsieh, S. S.; Chang, Y. K.; Huang, C. J.; Hillman, C. H.; Hung, T. M. Up-Regulation of Proactive Control Is Associated with Beneficial Effects of a Childhood Gymnastics Program on Response Preparation and Working Memory. *Brain Cogn.* **2021**, *149*. https://doi.org/10.1016/j.bandc.2021.105695.
25. Rudd, J.; Buszard, T.; Spittle, S.; O'Callaghan, L.; Oppici, L. Comparing the Efficacy (RCT) of Learning a Dance Choreography and Practicing Creative Dance on Improving Executive Functions and Motor Competence in 6–7 Years Old Children. *Psychol. Sport Exerc.* **2021**, *53* (November 2020), 101846. https://doi.org/10.1016/j.psychsport.2020.101846.
26. Mondéjar, T.; Hervás, R.; Johnson, E.; Gutierrez, C.; Latorre, J. M. Correlation between Videogame Mechanics and Executive Functions through EEG Analysis. *J. Biomed. Inform.* **2016**, *63*, 131–140. https://doi.org/10.1016/j.jbi.2016.08.006.
27. Sánchez-Pérez, N.; Castillo, A.; López-López, J. A.; Pina, V.; Puga, J. L.; Campoy, G.; González-Salinas, C.; Fuentes, L. J. Computer-Based Training in Math and Working Memory Improves Cognitive Skills and Academic Achievement in Primary School Children: Behavioral Results. *Front. Psychol.* **2018**, *8* (JAN). https://doi.org/10.3389/fpsyg.2017.02327.
28. Özçetin, M.; Gümüstas, F.; Çag, Y.; Gökbay, I. Z.; Gökbay, A. The Relationships between Video Game Experience and Cognitive Abilities in Adolescents. *Neuropsychiatr. Dis. Treat.* **2019**, *15*, 1171–1180. https://doi.org/10.2147/NDT.S206271.
29. Song, H.; Yi, D. J.; Park, H. J. Validation of a Mobile Game-Based Assessment of Cognitive Control among Children and Adolescents. *PLoS One* **2020**, *15* (3), 1–18. https://doi.org/10.1371/journal.pone.0230498.
30. Sheehan, D. P.; Katz, L. The Effects of a Daily, 6-Week Exergaming Curriculum Onbalanceinfourthgrade Children. *J. Sport Heal. Sci.* **2013**, *2* (3), 131–137. https://doi.org/10.1016/j.jshs.2013.02.002.
31. Barnett, L. M.; Ridgers, N. D.; Reynolds, J.; Hanna, L.; Salmon, J. Playing Active Video Games May Not Develop Movement Skills: An Intervention Trial. *Prev. Med. Reports* **2015**, *2*, 673–678. https://doi.org/10.1016/j.pmedr.2015.08.007.
32. McGlashan, H. L.; Blanchard, C. C. V.; Nicole, J. S.; Lee, R.; French, B.; Sycamore, N. J. Improvement in Children's Fine Motor Skills Following a Computerized Typing Intervention. *Hum. Mov. Sci.* **2017**, *56* (December 2016), 29–36. https://doi.org/10.1016/j.humov.2017.10.013.
33. Gomes, J. Z.; Barbosa, J. L. V. Research Clusters of Ubiquitous Intelligent Services to Vehicular Users. *WebMedia 2018 - Proc. 24th Brazilian Symp. Multimed. Web* **2018**, 65–68. https://doi.org/10.1145/3243082.3267450.
34. van Eck, N. J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84* (2), 523–538. https://doi.org/10.1007/s11192-009-0146-3.