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Improving cognition in school children and adolescents through exergames. A systematic review and practical guide

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Recent studies and reviews have shown the positive effects of exergames (EXs) on physical activity (PA) and fitness in children and adolescents. Nevertheless, their effects on cognition have been scarcely explored, and no previous review has focussed on this relationship. The purpose of the research reported on here was to analyse the acute and chronic effects of the use of different EXs on the cognition of young people aged 6 to 18 years, to review potential confounders, and to elaborate a practical guide to using EXs in schools or extracurricular contexts. Studies were identified from 4 databases (Pubmed, SportDiscus, ProQuest and Web of Science) from January 2008 through January 2018. Thirteen studies met the inclusion criteria. All the studies showed a positive effect of EXs on cognition. The review showed an acute improvement effect on executive functions (EFs) (visual attention, mental processing, working memory, response inhibition, and motor planning) and chronic benefits on mathematical calculation, self-concept, classroom behaviour, and on parental and interpersonal relationships. Only 5 studies used confounders. EXs are an effective and motivating tool to improve cognition in young people aged 6 to 18 years. Didactic recommendations to use EXs in school or extracurricular contexts are provided in this article.

Keywords: academic performance; active video games; acute and chronic effects; cognitive performance; executive functions; exergames; learning; motivation; physical activity; physical education

Introduction

Theoretical Framework of Cognition and Physical Activity

Cognition is a multifactorial mental capacity that allows people to plan and develop actions based on intellectual organisation and behaviour control (Ruiz-Ariza, Grao-Cruces, De Loureiro & Martínez-López, 2017). In young people, cognitive ability is related to cognitive performance (CP) and academic performance (AP). CP is determined by physiological factors such as inhibitory control and EFs (selective attention, concentration, planning/organisation of materials) (Haapala, Poikkeus, Kukkonen-Harjula, Tompuri, Lintu, Väistö, Leppänen, Leaksonen, Lindi & Lakka, 2014; Swanson, 2005). In addition, executive functioning includes higher-order thinking skills that also play a role in CP such as perception and memory (Baniqued, Kranz, Voss, Lee, Cosman, Severson & Kramer, 2014). For its part, AP refers to the success of a student during the academic stage and may be mediated by behavioural factors such as study strategies (Caso-Niebla & Hernández-Guzmán, 2007; Ruiz-Ariza et al., 2017), teachers' assessment of attendance, participation and attitudes in class, or parents' educational level (Castillo, Ruiz, Chillón, Jiménez-Pavón, Esperanza-Díaz, Moreno & Ortega, 2011). Overall, the level of cognition in children and adolescents is considered key to personal development, as it has a decisive influence on school success and improved future job success (Tomporowski, 2016).

Although some previous research raised controversy regarding the positive effect of PA on CP or AP (Ahamed, Macdonald, Reed, Naylor, Liu-Ambrose & McKay, 2007; Ruiz, Ortega, Castillo, Martín-Matillas, Kwak, Vicente-Rodríguez, Noriega, Tercedor, Sjöström & Moreno, 2010; Stroth, Kubesch, Dieterle, Ruchsow, Heim & Kiefer, 2009), more recent studies have demonstrated that the systematic practice of PA can contribute to the improvement of CP variables such as concentration, attention and memory, as well as increase the AP (De Sousa, Medeiros, Del Rosso, Stults-Kolehmainen & Boullosa, 2019; Ruiz-Ariza et al., 2017). However, physical inactivity and sedentarism levels continue to rise and three out of four adolescents do not reach the daily-recommended amount of PA (Mielgo-Ayuso, Aparicio-Ugarriza, Castillo, Ruiz, Ávila, Aranceta-Batrina, Gil, Ortega, Serra-Majem, Varela-Moreiras & González-Gross, 2016). Thus, it seems very important to look for novel strategies to motivate young people to be more physically active (Dalais, Abrahams, Steyn, De Villiers, Fourie, Hill, Lambert & Draper, 2014; Joronen, Aikasalo & Suvitie, 2017).

The Exergames as an Alternative to Increase Physical Activity

Currently, young people are considered digital natives because they have incorporated into their lifestyle the use of new technologies (Prensky, 2001). During the 21st century, the use of mobile phones, tablets and other digital resources such as video games have spread throughout the world and are being implanted as strategies for learning (Osang, Ngole & Tsuma, 2013). The use of these devices generates an intrinsic motivation and has become the main means of communication among young people (Buckley & Doyle, 2016; Sun & Gao, 2016).

In fact, many past studies have indicated the successfulness of different games for cognitive stimulation (All, Nuñez Castellar & Van Looy, 2016; Bavelier, Bediou & Green, 2018). All think that serious games are effective compared to traditional instruction, but not all games equally impact cognition (Bediou, Adams, Mayer, Tipton, Green & Bavelier, 2018) and the effectiveness can be improved (Wouters & Van Oosterndorp, 2017).

Other recent studies have shown that using active video games or EXs can be a novel strategy to increase PA levels in youths (Jelsma, Geuze, Mombarg & Smits-Engelsman, 2014); indeed, they show a high rate of popularity among young people. The interactive dynamics of EXs allow users to generate an attractive connection between digital play and physical play (LeBlanc & Chaput, 2016; Nigg, Mateo & An, 2016). For this to occur, the EXs interpret body movements of the player by sensors, some projecting every move on a television monitor (e.g., Dance Dance Revolution [DDR], Nintendo Wii, or Xbox) or others promoting interactivity by smartphone (e.g., Pokémon GO, Zombies, Run!, The Walking Dead: Our World or Harry Potter: Wizards Unite). In addition, these games increase motivation for the practice of PA and physical fitness (Nurkkala, Kalermo & Jarvilehto, 2014; Smits-Engelsman, Jelsma & Ferguson, 2017), caloric expenditure (Barnett, Cerin & Baranowski, 2011), and promoting social relationships among peers (Roemmich, Lambiase, McCarthy, Feda & Kozlowski, 2012). Despite this, the multiple possibilities of the use of the EXs (daily play time, EX mode, intensity, type of exercise, etc.) have scarcely been analysed, and the effects of this type of PA may differ depending on variables such as gender, age, body mass index (BMI) or socioeconomic status (Ruiz-Ariza et al., 2017).

Proposal Justification and Research Aims

Previous reviews have studied the effect of using EXs in children and adolescents. Norris, Hamer and Stamatakis (2016) studied the effects of EXs on motor skills, PA, and health outcomes. Joronen et al. (2017) focussed more specifically on the non-physical effects of EXs, such as self-concept, motivation, enjoyment, or psychological and social well-being. However, no previous systematic reviews have considered their impact on cognition. Thus, the question posed in this study was the following: Can the use of EXs predict improved cognition in children and adolescents? A study of the specific influence offered by EX, with their different singularities in the CP and AP of children and adolescents, and an analysis of the possible influence of confounding covariates, has never been conducted.

Based on the above, the objective of this research was to analyse the acute and chronic effects of using different EXs on the cognition of young people aged 6 to 18 years. Additionally, with this article we intended to: 1) elaborate didactic recommendations for using EXs in school or in extracurricular contexts, with regard to their benefits on cognition; and 2) provide practical considerations for teachers and parents on how they can contribute to the development of new PA programs motivating children and adolescents and helping EXs to be perceived as useful educational tools.

Method

Study Design

As design for the study, we followed the structure and suggestion of similar recent systematic reviews (Norris et al., 2016; Ruiz-Ariza et al., 2017) and the treatment recommended by PRISMA guidance (Beller, Glasziou, Altman, Hopewell, Bastian, Chalmers, Gøtzsche, Lasserson & Tovey, 2013). Databases, search strategies and limits, and filtered papers are shown according to Cochrane's indications for systematic reviews of interventions (Higgins & Green, 2011) to allow replication of each study.

Search Limits

A comprehensive and widespread search of four databases of literature (PubMed, SportDiscus, Web of Science, and ProQuest) was carried out from January 2008 to the end of January 2018. In addition, bibliographical references of the different studies were analysed. The combinations of terms were: 1) EXs (Active Video Game, Dance Dance Revolution, Pokémon GO, Nintendo Wii, PlayStation, Geocaching); 2) cognition measures (cognitive, mental, psychological, academic, cognition, academic outcomes, executive function); and 3) children and adolescents (elementary school, childhood, children, teenagers, adolescents).

Selection Criteria

The criteria to include the most pertinent studies for the review were: 1) The paper had been published in full text and in a peer-reviewed journal, 2) the paper included a healthy population, 3) the selected EX and cognition measures were described clearly, 4) the population consisted of children or adolescents from 6 to 18 years of age, 5) the study was of interventional or longitudinal design, and 6) data were adjusted for confounders.

Data Extraction and Reliability

Three independent reviewers (SLS, ARA, EJML) performed the search process. They read the titles and abstracts, and arranged a meeting in which they resolved any differences between them. Information about the author, title, aim, sample size, age, country, design, EX measurement, EF measurement, confounders, and main results/conclusions was extracted from each study.

Firstly, the results of the most recent reviews were summarised. Thereafter, papers that were significant for the selected themes were screened using the flowchart.

Quality Assessment and Level of Evidence

To evaluate the quality level of the studies, an assessment list based on previous standardised quality lists was used (Joronen et al., 2017; Ruiz-Ariza et al., 2017). Additionally, we took our own specific selection criteria into account. The list consisted of six items on blinding, population, measurements, age, design, and confounders. Each item was rated as “2” (fully reported), “1” (moderately reported), or “0” (not reported or unclear). A total quality score incorporating all positive items was calculated for all studies (a total score of 0–12). Three levels of evidence were classified. Studies were defined as low quality (LQ) if they had a total score less than five. A total score of five to eight was defined as medium quality (MQ), and a score of nine or higher was defined as high quality (HQ) (see Table 1).

Table 1 Shows the main terms used in the search for each category (own creation)

Database	Search strategy	Limits	Filter
PubMed	**AB/TS=/ab** (((active video game OR exergame OR dance simulation OR Pokémon GO OR Nintendo OR Wii OR PlayStation OR	-Publication date from 2008/01/01 to 2018/01/01 -Humans	75 items
SportDiscus (EBSCO)	Geocaching) AND **AB/TS=/ab** (cognitive OR mental OR psychological OR academic OR cognition OR academic outcomes OR executive	-Preschool Child: 2–5 years -Children: 6–12 years -Adolescent: 13–18 years	54 items
Web of Science	function)) AND **AB/TS=/ab** (adolescents OR teenagers OR children OR childhood OR	-English language -Peer-reviewed	95 items
ProQuest	elementary school)))	-Article or review	74 items

Results

The flow of search findings through the systematic review process is shown in Figure 1. Two hundred and ninety-eight studies resulted from an initial search. After an initial review, we dispensed with duplicate articles based on the abstracts (population, language or design) if they were not aligned with our inclusion criteria. Of the 37 articles selected for a second review, 24 were discarded after reading because they failed to meet any inclusion criteria. Finally, 13 intervention studies were included in the systematic review (see Table 2). Regarding to quality assessment, nine studies were of HQ and four were of MQ.

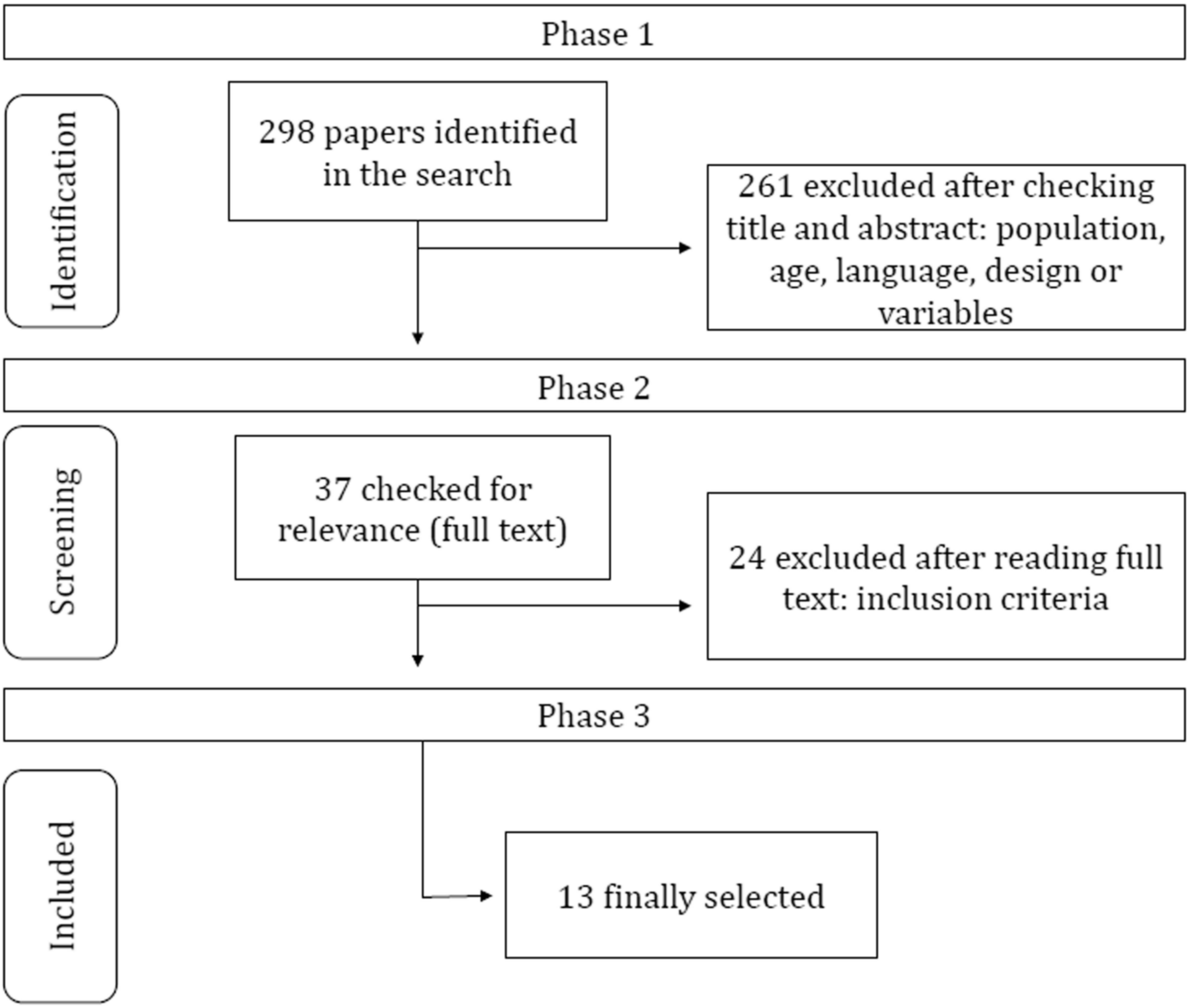

Figure 1 Flowchart of search results and study selection process (own creation)

Table 2 List of publications with quality scores (own creation)

Authors and variables	A	B	C	D	E	F	Total score	Quality level
Anderson-Hanley, Tureck and Schneiderman (2011). Autism and EX.	2	0	1	2	2	0	7	MQ
Staiano and Calvert (2011). EX and EF.	2	0	2	2	2	0	8	MQ
Best (2012). EX and EF.	2	2	2	2	2	0	10	HQ
Wagener, Fedele, Mignogna, Hester and Gillaspy (2012). Psychological effects of dance EX.	2	0	1	2	2	0	7	MQ
Gao, Zhang and Stodden (2013). PA, psychological and dance.	2	2	2	2	2	0	10	HQ
Gao, Hannan, Xiang, Stodden and Valdez (2013). AVG and physical health and academic achievement.	2	2	2	2	2	2	12	HQ
Flynn, Richert, Staiano, Wartella and Calvert (2014). EX and EF.	2	1	2	2	2	0	9	HQ
Hilton, Cumpata, Klohr, Gaetke, Artner, Johnson and Dobbs (2014). EX, EF and motor skills.	2	0	2	2	2	0	8	MQ
Lisón, Cebolla, Guixeres, Álvarez-Pitti, Escobar, Bruñó, Lurbe, Alcañiz and Baños (2015). AVG, physiological and psychological responses.	2	2	2	2	2	2	12	HQ
Sun and Gao (2016). AVG, motivation, science knowledge and PA.	2	2	1	2	2	0	9	HQ
Gao, Lee, Pope and Zhang (2016). AVG, Classroom behaviours, effort and fitness.	2	2	2	2	2	0	10	HQ
Benzing and Schmidt (2017). EX, PA and EF.	2	2	2	2	2	2	12	HQ
Ruiz-Ariza, Casuso, Suarez-Manzano and Martínez-López (2018). AR, Pokémon GO, CP, EI and adolescents.	2	2	2	2	2	2	12	HQ

Note. Rating for total score: high quality (HQ) = 9–12; medium quality (MQ) = 5–8; low quality (LQ) = 0–4. AVG = Active Video Games. AR = Augmented Reality. EI = Emotional Intelligence. A = The paper was published in full text and in a peer-reviewed journal. B = The paper included a healthy population. C = The selected EXs and cognition measures were clearly described. D = Population was of children or adolescents between 2 and 18 years of age. E = The study had a longitudinal or interventional design. F = Data were adjusted for confounders.

This systematic review embraces data from 1,006 youths; the sample size varied from 22 (Anderson-Hanley et al., 2011) to 208 (Gao, Hannan, et al., 2013) participants. Three studies were conducted in Spain (Benzing & Schmidt, 2017; Lisón et al., 2015; Ruiz-Ariza et al., 2018), and 10 in the United States (Anderson-Hanley et al., 2011; Best, 2012; Flynn et al., 2014; Gao, Hannan, et al., 2013; Gao et al., 2016; Gao, Zhang, et al., 2013; Hilton et al., 2014; Staiano & Calvert, 2011; Sun & Gao, 2016; Wagener et al., 2012). Detailed information about all the research is shown in Table 3.

Table 3 Characteristics of the analysed studies ($N = 13$) (own creation)

Authors and variables	Study objective	Study design / Confounders / Duration	Sample / Age / Country	Exergames measures	Cognitive measures	Results
Anderson-Hanley et al. (2011). Autism and EX.	To explore the potential behavioural and cognitive benefits of exergaming in two pilot studies.	Intervention / Participants were exposed to both CG and EG in an A–B sequential design / – / 20 min.	Study I: *N* = 12 /10–18 years / Study II: *N* = 10 / 8–21 years / USA	Study I: Control session 20 min video of a previously recorded school talent show. Exergaming Session 20 min DDR. Study II: Control session 20 min video of a previously recorded school talent show. Exergaming session 20 min of cyber cycling. Non-randomised.	Digit span forward (verbal and visuospatial short-term memory). Backward color trails test (attention, divided attention, speed of mental processing). The Stroop Task (working memory and attention).	Significant improvement after exergaming (for both DDR and cyber cycling) compared with the CG, for repetitive behaviour and EFs. (Pilot I: Behaviour $p = 0.001$, Digits Backward $p = 0.03$, Stroop $p = 0.04$ / Pilot II: Behaviour =0.03, Digit Backward $p = 0.03$).
Staiano and Calvert (2011). EX and EF.	To analyse the short-term effects of playing Nintendo Wii in competitive, cooperative, or no-play condition on the EF skills of low-income African-American overweight and obese students.	Intervention/ – /10 weeks	*N* = 54/15–19/USA	Nintendo Wii EA Sports active. Group 1. Competitive condition (compare their fitness progress with others). Group 2. Cooperative condition (work together to progress as teams). Group 3. Youths continued their typical activities (30 min during recess). Non-randomised.	D-KEFS (visual-spatial skills, visual acuity, visualisation, task switching, perceptual speed, response inhibition, motor planning, visual scanning, speed, and cognitive flexibility)	Group 1 improved in D-KEFS total scores significantly more than Group 2 ($p = 0.020$) or Group 3 ($p = 0.018$) in EF.
Best (2012). EX and EF.	To examine if the PA with EX may contribute to children's EF.	Intervention/ – /4 hours	*N* = 33/ 6–10 years / USA	Study I: 2 HR (Nintendo Wii "Active Life" versus sedentary activities). Study II: 2 HR (Games requiring challenging, adaptive play versus sedentary activities). Non-randomised.	ANT-C (visual attention)	A single bout of exergaming enhances children's EF ($p < 0.01$).
Wagener et al. (2012). Psychological effects of dance EX.	To investigate the impact of dance-based EX on a diverse sample of obese adolescents' perceived competence in exercise, psychological adjustment and BMI.	Intervention/ – /10 weeks	*N* = 40 / 12–18 years / USA	EX Group. Each session was 75 min divided into four 15 min exergaming segments/CG. The wait-list controls were asked to not modify their baseline activity levels during the 10 weeks. Randomised.	PCS (sense of competence cognitive, social, physical and self-worth), BASC-2, PRS-A and SRP-A (internalising and externalising symptomatology, social stress, relationship with parents, interpersonal relationships, social skills/pro-social behaviours).	EX Group significantly increased in self-reported perceived competence to exercise regularly ($p = 0.02$), relations with parents from baseline to end-of-treatment ($p = 0.02$) and SRP-A test ($p = 0.04$) respect CG. No pre-post differences in BMI were seen within or between conditions.
Gao, Zhang, et al. (2013). PA, Psychological and	To compare children's PA levels, self-efficacy, and	Intervention/ – /9 month	*N* = 53 /10–11 years/USA	All children participated in the PA program playing at DDR, aerobic dance (nine lesson about	Self-efficacy Likert-type scale.	Children spent more MVPA time ($p < 0.01$) in aerobic dance than DDR. Additionally, children

Authors and variables	Study objective	Study design / Confounders / Duration	Sample / Age / Country	Exergames measures	Cognitive measures	Results
Dance.	enjoyment when experiencing dance-exergaming and aerobic dance.			30 min). Non-randomised.		reported significantly higher self-efficacy ($p < 0.001$) and enjoyment ($p < 0.01$) in DDR than in aerobic dance.
Gao, Hannan, et al. (2013). AVG and Physical health and Academic achievement.	To examine the impact of DDR-based exercise on Latino children's physical fitness and academic achievement.	Intervention/ gender and age /2 years	N = 208 /10–12 years/USA	Group 1. Recess based in 15 min of DDR and others 15 min participated in activities during the school day. Group 2 and 3. Participated in the conventional unstructured recess. Non-randomised.	Utah Criterion Referenced Test (Academic knowledge and skills related to specific subject areas)	Significant differences between Group 1 and Groups 2 and 3 in maths scores test in Year 1 and Year 2 ($p = 0.01$).
Flynn et al. (2014). EX and EF.	To examine the use of an EX to increase EF skills in a diverse sample of youths from low-income and high rates of childhood obesity.	Intervention/ – /5 weeks	N = 70 / 10–16 years/USA	All children participated divided in four groups. Five possible Nintendo Wii Fit classes (30 min). Randomised Group.	D-KEFS (visual–spatial skills, visual acuity, visualisation, task switching, perceptual speed, response inhibition, motor planning, visual scanning, speed, and cognitive flexibility)	Children who played the EX during 5 weeks demonstrated improvements in D-KEFS post-test ($p < 0.05$). Additionally, children who played for more sessions experienced larger growth in EF ($p < 0.001$).
Hilton et al. (2014). EX, EF and Motor skills.	To analyse the effects of Makoto Arena Training intervention (a light and sound speed-based EX), on response speed, EF, and motor skills in school-aged children with ASD.	Intervention/ – / 30 sessions	N = 61/7–12 years/USA	Makoto Arena Training. Three sessions per week (2 min per session). Non-randomised.	BRIEF (EF abilities: Inhibit, shift, emotional control, initiate, working memory, plan/organise, organisation of materials). Wechsler Abbreviated Scale of Intelligence.	Significant improvement was seen in the EF areas of working memory and metacognition (p = 0.029).
Lisón et al. (2015). AVG, Physiological and Psychological responses.	To determine whether adding a competitive component to playing AVG influences physiological and psychological responses in players.	Intervention/ treadmill walking, single-player and opponent-based Kinect Adventures Game / 24 min	N = 62/9–14 years/ Spain	Group 1. Treadmill walking walked (two speeds: 4.2 and 5.7). Group 2. Xbox Kinect Adventures Game (Single Player). Group 3. Opponent based Xbox Kinect Adventures Game. 8 min each group. Randomised Group.	The Feeling Scale (affective valence). Felt Arousal Scale (perceived activation). Eston-Parfitt RPE scale (perceived exertion).	Group 3 revealed significantly higher rates of perceived exertion when compared with Group 1 ($p <$ 0.001). No significant differences Group 2 ($p = 0.183$).
Sun and Gao (2016). AVG, Motivation, Science Knowledge and PA.	To identify the effectiveness of an AVG on elementary school students' science knowledge	Intervention/ – /2 weeks	N = 53/7–11 years/USA	CG played "Earth, Moon, and Sun. An interactive learning experience". EG played GZ Pro-Sport. Randomised Group.	Situational Interest Scale (Attention demand, challenge, exploration intention, instant enjoyment, and novelty).	Science knowledge test showed that students in both groups performed better on the post-test ($p < 0.001$). EG perceived a higher level on Situational Interest Scale

Authors and variables	Study objective	Study design / Confounders / Duration	Sample / Age / Country	Exergames measures	Cognitive measures	Results
	learning, PA level, and interest-based motivation.					($p < 0.01$).
Gao et al. (2016). AVG, Classroom behaviours, Effort and Fitness.	To examine the effect of AVGs on underserved minority children's on-task classroom behaviour, academic effort, and fitness.	Intervention/ – /6 weeks.	N = 95 / 10–11 years/USA	All children participated in the PA program. Nintendo Wii, Xbox 360 "Wii Just Dance, Wii Sports, Wii Fit, and Kinect Sport". 50 min peer week. Non-randomised.	TRAAM Scale changing the wording to fit the AVG study (Children's classroom behaviour, attention and conduct, social/emotional behaviour, and other behaviours).	There was a significant effect between the first and last week on children's effort ($p = 0.02$) and classroom behaviour ($p < 0.01$). However, no main effect was indicated for gender ($p = 0.54$).
Benzing and Schmidt (2017). EX, PA and EF.	To analyse the influence of CE comprised in an acute bout of EX based PA on EF in adolescents.	Intervention/ Age, BMI, pubertal status, socioeconomic status, PA behaviour/15 min.	N = 65/13–16/Spain.	Group 1. Xbox Kinect Shape Up. PA with high levels of CE. Group 2. PA with a low level of CE. Group 3. Sedentary with a low level of CE. Randomised Group.	D-KEFS (Visual spatial skills, visual acuity, visualisation, task switching, perceptual speed, response inhibition, motor planning, visual scanning, speed, and cognitive flexibility)	Group 1 required more CE effort than Group 2 ($p = 0.022$) and Group 3 ($p = 0.001$). No differences between Group 2 and Group 3 ($p = 0.201$).
Ruiz-Ariza et al. (2018). Augmented reality, Pokémon GO, Cognitive performance, and EI in adolescents.	To analyse the effect of Pokémon GO on cognitive performance and EI in adolescents.	Intervention/ Age, sex, BMI, maternal educational level, number of computers at home and MVPA/8 weeks	N = 190 / 12–15 years / Spain	EG played Pokémon GO Game for Mobile Phone. CG did not use Pokémon GO. Non-randomised.	Ad hoc test from Spanish adaption of the Reynolds Intellectual Assessment Scales test and Poster of Spanish playing cards (memory). Test d2 (Selective attention and concentration capacity). Ad hoc tests of mathematical calculation and linguistic reasoning. TEIQue-SF (EI).	The players playing Pokémon GO significantly increased their selective attention ($p = 0.003$), concentration levels ($p < 0.001$), and sociability levels ($p = 0.003$) as opposed to their peers.

Note. CG = Control Group. EG = Experimental Group. Minute = min. USA = United States of America. D-KEFS = Delis-Kaplan Executive Function System. HR = Heart Rate. ANT-C = Child Attention Network Test. PCS = Perceived Competence Scale. BASC-2 = Behavior Assessment System for Children 2. PRS-A = Parent Rating Scales-Adolescents Version. SRP-A = Adolescent Self-Report Scales. MVPA = Moderate to Vigorous Physical Activity. ASD = Autism Spectrum Disorder. BRIEF = Behavior Rating Inventory of Executive Function. RPE = Rating of Perceived Exertion. GZ = Gamercize. TRAAM = Teacher Rating of Academic Achievement Motivation. CE = cognitive engagement. TEIQue-SF = Trait and Emotional Intelligence Questionnaire Short Form.

Acute Effect of Exergames on Cognition Measures

Four studies analysed the acute effect of EX on cognition. Anderson-Hanley et al. (2011) conducted two pilot studies of 20 min each. An EG practised DDR and Cyber Cycling. In both cases, EFs such as attention speed, mental processing, and short-term working memory improved ($p < 0.001$ and $p = 0.03$, respectively), compared to a CG (who viewed a video of the same duration). Best (2012) found that children between 6 and 10 years who participated in two bouts of 10 min (with a break to drink water) of an exergame titled Marathon (Namco Bandai, Santa Clara, California [CA]) for the Nintendo Wii, improved the speed at which children resolved interference from conflicting visuospatial stimuli. Lisón et al. (2015) found that 20 min of competitive practice of Xbox Kinect Adventures increased psychological responses, as perceived immediate activation and perceived exertion, when compared to a CG that only walked ($p < 0.001$). Finally, Benzing and Schmidt (2017) found significant differences in perceptual speed, response inhibition, motor planning, and cognitive flexibility after 15 min of game playing. The differences were between the group who practised PA through Xbox Kinect with high levels of CE, as opposed to a group that practised it with low levels of CE ($p = 0.022$), and a sedentary group with low levels of CE during passive video watching ($p = 0.001$). The literature includes other benefits derived from short-term practice of EXs. For example, participants increased their scores on self-esteem, social behaviour, and motor skills compared to those who continued with their daily tasks (Anderson-Hanley et al., 2011; Benzing & Schmidt, 2017).

Chronic Effect of Exergames on Cognition Measures

A total of nine studies analysed the chronic effect of EXs on CP. Intervention periods varied between 2 weeks and 2 years, establishing a duration per session between 2 and 75 min and with a moderately-vigorous intensity. Staiano and Calvert (2011) concluded that young people who played Nintendo Wii competitively (comparing their fitness progress with others) for 10 weeks improved EFs in such areas as visual-spatial skills, visual acuity, planning, visual scanning, and cognitive flexibility, when compared to a cooperative EX group who progressed as a team ($p = 0.020$) and a CG that carried out everyday tasks ($p = 0.018$). Wagener et al. (2012) investigated the impact of dance-based exergaming during a 10-week period. They found that adolescents who used EX improved parental relationships and self-concept, compared to a wait-list CG ($p = 0.02$). Gao, Hannan, et al. (2013), after 2 years of study, determined that continued work with DDR increased math scores, compared to a CG ($p = 0.01$). In a similar study (Gao, Zhang, et al., 2013), the authors concluded that after 9 months of DDR, young people improved self-concept and enjoyed their lives more than an aerobic dance-based group ($p < 0.001$, $p < 0.01$, respectively). For Flynn et al. (2014), children who played Nintendo Wii for 5 weeks improved visual-spatial skills, perceptual speed, motor planning, and cognitive flexibility ($p < 0.05$), increasing the significance if they participated in additional sessions ($p < 0.001$). On the other hand, Sun and Gao (2016), carried out a 2-week study at an elementary school. The EG was exposed to an active educational game learning environment, whereas the other group performed a sedentary video game (Earth, Moon, and Sun, an interactive learning experience). Both groups achieved better results on the knowledge post-test ($p < 0.001$), but the EG displayed a higher level of situational interest ($p < 0.01$). Recently, Gao et al. (2016) observed that after 6 weeks of activities with children with different EXs (Nintendo Wii or Xbox) during the 50 min lunch recess, participants improved behaviour in class ($p < 0.01$). Ruiz-Ariza et al. (2018) analysed the effect of 8 weeks of Pokémon GO on CP and EI in adolescents. Children playing Pokémon GO increased their selective attention ($p = 0.003$), concentration ($p > 0.001$), and sociability levels ($p = 0.003$), as opposed to their peers. In addition to the benefits indicated above, the systematic practice of PA through EXs helps improve other variables such as self-esteem, social behaviour, self-efficacy, coordination, and motor skills (Flynn et al., 2014; Gao, Zhang, et al., 2013; Nurkkala et al., 2014), regardless of the type of EX used (see Table 3).

Practical Analysis of the Most Important Acute-Chronic Findings regarding Exergames and Cognition in Young People

Among the most outstanding acute effects of EX on cognition, we highlight that practising 15 to 20 min of Xbox Kinect, DDR, Cyber Cycling, or EX Marathon for the Nintendo Wii, can improve EFs such as attention, perceptual speed, response inhibition, motor planning, cognitive flexibility, the speed at which interference from conflicting visuospatial stimuli is resolved, mental processing, psychological responses, as perceived immediate activation and perceived exertion, and short-term working memory (Anderson-Hanley et al., 2011; Benzing & Schmidt, 2017; Best, 2012; Lisón et al., 2015).

On the other hand, as among the most outstanding chronic effects of EX on cognition, research suggests a practise period of 20 to 30 to 50 min/day, 1 to 3 days per week, for 4 to 10 weeks at 77% to 90% maximal HR, using the Nintendo Wii Sport, Wii Just Dance, Wii Fit, or Xbox Just Dance (Flynn et al., 2014; Gao et al., 2016; Staiano & Calvert, 2011). To perform this activity, classes can be organised into stations, with each station accommodating the gameplay of two children and children rotating from one station to another every 10 to 15 min (Gao et al., 2016). Other proposals are to perform a dance-based EX (i.e. DDR), with two to four bouts of 15 min and rest breaks of 5 min (in sessions of 40–75 min), 3 days per week, for 10 weeks at 75% maximal HR (Wagener et al., 2012), or for 30 min per day, 3 days per week, for 9 months (Gao, Zhang, et al., 2013) or 2 years (Gao, Hannan, et al., 2013). In general, within the school context, EX routines could be taught in Physical Education (PE) classes, in the lunch recess period, or in usual classes (Flynn et al., 2014; Gao et al., 2016; Smits-Engelsman et al., 2017). Moreover, the EX could be performed in an extracurricular schedule, for example, through the use of the novelty AR game, Pokémon GO. In this sense, a recent study suggests playing Pokémon GO for 40 min per day, every day for 8 weeks to increase CP (Ruiz-Ariza et al., 2018). The different EXs above use and improve the EFs of young people in such areas as visual-spatial skills, visual acuity, planning, visual scanning, selective attention, concentration, perceptual speed, motor planning, cognitive flexibility, and maths scores.

In addition to the benefits indicated, the acute or chronic practice of PA through EXs helps to improve other variables, such as self-efficacy, self-esteem and self-concept, sociability and social behaviour, parental relationships, enjoyment of life, behaviour in class, perceived competence to exercise, coordination, and motor skills (Anderson-Hanley et al., 2011; Benzing & Schmidt, 2017; Flynn et al., 2014; Gao, Zhang, et al., 2013, 2016; Nurkkala et al., 2014; Wagener et al., 2012).

Discussion

Through this systematic review we investigated the effects of EXs on cognition in children and adolescents. Studies from January 2008 through to January 2018 were extracted from four databases. A total of 13 intervention studies met the inclusion criteria. Fifteen to 20 min of EXs produced improvements in visual attention, mental processing, working memory, response inhibition, motor planning, and cognitive flexibility. The studies that analysed the chronic effects of EXs (20–50 min per day, 1 to 3 days per week, for 4 to 10 weeks at 75% to 90% maximal HR, or even prolonging the intervention for 9 months or 2 years) showed improvements in other academic variables, such as mathematical calculation, and personal factors (i.e., a higher self-concept, better classroom behaviour, improved parenting and interpersonal relationships, as well as higher self-efficacy, coordination, and motor skills). These results suggest that the inclusion and promotion of EX programs in educational contexts could positively impact the cognitive and academic development of young people.

Short-Term Considerations on Cognition Using Exergames

The acute effects found in the studies analysed have shown that EFs, self-esteem, and social behaviour obtained the highest scores after 15 to 20 min of EX activity. However, O'Leary, Pontifex, Scudder, Brown and Hillman (2011) found that four 20-min EX sessions could increase PA in adolescents, although with lower benefits for cognition than those obtained with PA practised in a traditional way. Block, Tooley, Nagy, O'Sullivan, Robinson, Colabianchi and Hasson (2018) showed that effects of several intensities of exercise and video game breaks cause the same performance in maths in children. Staiano and Calvert (2011) verified some of the effects studied in this review. Their results showed that some of the skills that youngsters can improve with the use of EX are spatial awareness; understanding spatial limitations and cause-effect interactions, adequate use of the smartphone, computer or videogames, correct answers to visual feedback; creation of a cognitive map of body movements in relation to the game; or self-improvement of concentration-attention – all of them determinants for better AP at educational centres.

Best (2012) explained how EXs could benefit cognition (especially EFs). This model was focused on the positive effect of EX on PA, motor skills, fitness or cognitive variables necessary for the game. It is difficult to make comparisons, given that few studies have researched the effect of EXs on cognition in children and adolescents. In other populations, such as older adults, Monteiro-Junior, Da Silva Figueiredo, De Tarso Maciel-Pinheiro, Abud, Montalvão Braga, Barca, Engedal, Nascimiento, Deslandes and Laks (2017) showed that a single session using Nintendo Wii EX produced no significant improvements in memory or EFs. These results differ from those found in older adults by Dimitrova, Hogan, Khader, O'Hora, Kilmartin, Walsh, Roche and Anderson-Hanley (2017). Their study investigated the effects of 20 min of strenuous PA by cyber cycle EX on cognition, in the track condition or in the game condition. In both conditions, EF performance improved ($p < 0.005$); no differences in EFs were found between the exercise conditions ($p = 0.44$).

Long-Term Considerations on Cognition Using Exergames

This review has also shown that chronic practice of EXs (20–50 min per day at 75–90% maximal HR, 1 to 3 days per week, for 4 to 10 weeks or even prolonging the intervention for 9 months or 2 years) produced an improvement in EFs and self-esteem, mathematics and science knowledge, better learning behaviour, greater interest in educational tasks, and improvements in social relationships. Although little research exists about the effect in young schoolchildren, the data from our review support results from other studies that analysed the effects of EXs on cognition in different populations. Confirmation of these results is especially important because, so far, these improvements have only been confirmed in reviews carried out on clinical patients and adults, where these areas are strongly correlated with functional disability (Marshall, Rentz, Frey, Locascio, Johnson, Sperling & Alzheimer's Disease Neuroimaging Initiative, 2011). For example, reviews by Chao, Scherer and Montgomery (2015) and Zeng, Pope, Lee and Gao (2017) showed that the use of EXs could be a good intervention strategy for physical, psychosocial, and cognitive benefits in older persons. Recently, a meta-analysis carried out by Stanmore, Stubbs, Vancampfort, De Bruin and Firth (2017) concluded that EXs affected EFs of participants between 17 and 88 years old. Specifically, these authors reported improvements in inhibitory control, cognitive flexibility, visual skills, attention, and speed of information processing. However, they did not find differential effects in language, spatial learning, memory, or verbal learning. Also, we must emphasise that most of the chronic studies carried out to date (e.g., Barnett et al., 2011; Höchsmann, Schüpbach & Schmidt-Trucksäss, 2016) have focussed on physiological improvement effects of different EX applications. In general, EXs (compared with traditional nonactive video games) increased energy expenditure, with a high to moderate intensity (Barnett et al., 2011; Lee, Kim, Park & Peng, 2017), HR and oxygen consumption (Biddiss & Irwin, 2010), increased PA levels, and decreased BMI (Höchsmann et al., 2016). More specifically, Maddison, Mhurchu, Jull, Jiang, Prapavessis and Rodgers (2007) showed that caloric expenditure increased between 129 and 400% after participants played PlayStation. Along these lines, with DDR, the participants doubled energy intake compared with a CG that played a sedentary videogame (Lanningham-Foster, Jensen, Foster, Redmond, Walker, Heinz & Levine, 2006).

Possible Physiological and Psychosocial Causes for the Improvement of Cognition

The results of this review cannot show why the EXs contribute to the improvement of cognitive functions. However, there are some physiological and psychosocial reasoning measures that would allow such an explanation. Firstly, intrinsic practice of PA through EXs can increase energy expenditure and PA levels at recommended intensities (Barnett et al., 2011) and increased HR (Biddiss & Irwin, 2010). With respect to practice of acute PA, this can be seen as a psychoactive stimulant, affecting arousal, attention, and academic effort (Meeusen & De Meirleir, 1995). Secondly, moderate to vigorous PA (MVPA) during the use of EXs could stimulate synaptogenesis and the brain-derived neurotrophic factor, a balancer of brain plasticity and cell survival (Chang & Etnier, 2015; Piepmeier & Etnier, 2015). The above processes are involved in cognitive functions such as response speed, impulse control, attention, and behaviour control, producing improvement in CP (Keeley & Fox, 2009; Ruiz-Ariza et al., 2017). With regarding to psychosocial considerations, some researchers claim that the continuous use of EX over time has a positive effect on other variables such as sociability with parents and peers, quality of life and autonomy (Ruiz-Ariza et al., 2017). For example, the practice of Pokémon GO can be beneficial because it encourages young people with severe social withdrawal to go out to play (Kato, Teo, Tateno, Watabe, Kubo & Kanba, 2017; Tateno, Skokauskas, Kato, Teo & Guerrero, 2016).

Recommendations for Using Exergames in the School Context

From a practical point of view, we suggest that parents should be aware of the positive effects of proper use of EXs on their children's cognitive, health, and psychological well-being. In turn, teachers should promote programs to include EXs in the educational field to encourage the practice of PA. Thus, both groups' motivational capacity could be used for the cognitive and academic development of young people. Haapala et al. (2014) and Ruiz et al. (2010), in studies among Finnish and Spanish young people, showed that extracurricular PA does not disserve CP, but rather benefits it. The playing features of EXs make it an efficient tool to gamify the teaching-learning process in any subject (Buckley & Doyle, 2016). Motivation caused by the interactive dynamics of EXs can be used by schools to increase levels of PA in recesses, breaks between subjects, or individual classroom teaching (Foley & Maddison, 2010; Gao, Chen & Stodden, 2015; Norris et al., 2016). In this way, schools have new tools to combat high rates of physical inactivity associated with numerous public health problems. A study conducted by Janssen (2016) showed that substituting 1 hour of daily sedentary video games with 1 hour of daily EXs can reduce emotional problems by 6%, increase probability of life satisfaction by 4%, and increase the likelihood of having high pro-social behaviour (13%). The incorporation of EXs into PE can promote new learning processes and counteract other limitations of modern society (e.g., few sports facilities, long distance to the sports centres, etc.). Table 4 shows recommendations for PA using EXs both in the school context and as extracurricular activities (Felver, 2018).

Table 4 Didactic recommendations to obtain acute and/or chronic effects on cognition of young people using exergames in school or extracurricular context (own creation)

Exergames		Type effect	Application					Effect on cognition		Other benefits
Modality	Games recommended	After practice	Duration recommended of stimulus	Intensity	Time of day	Time effect	Age	Executive functions	Academic performance	
DDR	Dancing stage DDR	A	4–5 min/2–3 sessions/day	VPA	Between classes during the school day	+	6–18	*	N/E	Self-esteem Social behaviour
		C	20 min/day 3 days/week	MVPA	At the beginning of day/recess/ after school	++	6–18	**	N/E	Coordination Self-esteem Social behaviour
		C	45–75 min/day 3 days/week ≥ 10 weeks	MVPA	Recess/PE	+++	6–18	N/E	**	Coordination Self-esteem Self-efficacy Social behaviour
Nintendo Wii	Wii Fit: Active life EA sport DDR	A	20 min	MVPA	At the beginning of day/Recess	+	6–18	**	N/E	Motor skills Self-esteem
		C	45–60 min 1 day/week ≥ 5 weeks	MPA	Recess/PE	++	10–16	**	N/E	Motor skills Self-esteem
		C	30 min 1 day/week ≥ 10 weeks	VPA	After school/Recess	+++	6–18	**	N/E	Motor skills
Xbox	Kinect: Adventures Sport	A	25 min	VPA	At the beginning of day/recess	++	8–16	*	N/E	Motor skills
		C	60 min 2 days/week ≥ 2 weeks	MVPA	Recess/PE	+++	8–16	*	**	Motor skills
Mobile Phone App	Pokémon Go/ Aurasma app	A	15–20 min	MVPA	After school	+	8–16	*	N/E	Social behaviour
		C	45 min/day ≥ 8 weeks	MVPA	PE/after school	+++	8–16	*	**	Social behaviour
Makoto Arena Training		A	N/E	N/E	N/E	N/E	N/E	N/E	N/E	N/E
		C	30 min/day 3 days/week ≥ 10 weeks	VPA	At the beginning of day/Recess/ After school	+++	7–12	**	N/E	Strength Agility Self-esteem
Cyber cycling		A	20 min	VPA	At the	++	6–16	*	N/E	N/E

Exergames		Type effect	Application					Effect on cognition		Other benefits
Modality	Games recommended	After practice	Duration recommended of stimulus	Intensity	Time of day	Time effect	Age	Executive functions	Academic performance	
		C	N/E	N/E	beginning of day/During class/Recess/ After school N/E	N/E	N/E	N/E	N/E	N/E

Note. + = Immediate; ++ = following hours; +++ = following weeks; VPA = Vigorous physical activity; MPA = Moderate physical activity; * = Very Good; ** = Excellent; N/E = No Evidence.

EXs can thus be used as an educational tool for the development of interdisciplinary practices and, as a result, contribute to a comprehensive and dynamic teaching methodology. For example, 20 min of DDR at the beginning of 6 to 18 year olds' school day could have significant effects on the following hours, excellent long-term effects on EFs, and benefits in terms of coordination, self-esteem, and social behaviour.

EXs could, therefore, be adapted to new educational initiatives using educational video games with interactive systems based on role playing, or using game-based learning to improve AP. The former would increase sociability in secondary school (González-González & Blanco-Izquierdo, 2012), and the latter would incorporate technology based on movement and cooperative learning models (Hsiao & Chen, 2016). Current pedagogical theory shows that the combined use of new technologies and gamification increases motivation towards learning, especially collaborative work skills, and improves critical thinking, creativity, and problem solving (Adams Becker, Cummins, Davis, Freeman, Giesinger Hall, Ananthanarayanan, Langley & Wolfson, 2017). The value of EXs as an educational medium can be summarised in three major points: i) it allows integration of curricular elements through challenges, making the teaching-learning process more fun and motivational; ii) it allows for the creation of contexts where students can test, fail, hit, make mistakes, try and enjoy without any serious consequences to their real lives; and iii) it has been proven that students become involved in academic activities if the result is considered interesting, useful and the effort required by the activity is adequate (Parhiala, Torppa, Vasalampi, Eklund, Poikkeus & Aro, 2018). Today's digital natives were born in an era of knowledge and communication linked to computers, cell phones, and video games. Their dependence on these devices is so high that many educational, social and labour proposals that fail to account for this relationship could be doomed to fail (Hagenauer & Hascher, 2014; Ruiz-Ariza et al., 2018).

Strength and Limitation for this Study

As main strength, through this systematic review we examined the associations of EX with CP and AP, in an independent and combined way. However, we cannot show why the EXs identified improved cognitive functions. A more exhaustive analysis through meta-analysis could have accurately quantified our findings. We included peer-reviewed studies from different countries published over a period of 10 years. Another strength could be the use of a quality standardised assessment list. The review included interventional studies and potential confounders.

On the other hand, we can highlight possible limitations. The same significance was afforded researches who used small sample sizes as those who used larger samples. Other relevant databases, such as Education Resources Information Center (ERIC), were not taken into account for this review. Other limitations could be language bias and publication bias. However, in previous systematic reviews and reference lists we did not find any study with the adequate inclusion criteria for this review in a language other than English.

Conclusion

In conclusion, we found a total of 13 articles that examined the effects of EX on cognition in children and adolescents. Four studied the acute benefits thereof and nine examined the chronic benefits. The acute practice of 15 to 20 min of Xbox Kinect, DDR, Cyber Cycling, or Nintendo Wii, or the chronic practice of this stimulus over a prolonged period (1–3 days per week for 1–24 months at 75%–90% maximal HR) can improve important cognitive variables, such as EFs, as well as long-term improvement of academic maths scores. Additionally, EXs help improve other variables, such as self-efficacy, sociability, behaviour, and motor skills. In general, within the school context, the EX routines could be taught in PE classes, breaks between classes, during the lunch recess period, or during usual classes. EXs could also be performed in an extracurricular schedule, for example through the use of innovative AR games based on the phenomenon of Pokémon GO.

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Authors' Contributions

SLS, ARA and EJML carried out the search process, reviewed the databases and wrote the general manuscript. SLS and MJDC compiled the tables and reviewed the references. All authors reviewed the final manuscript.

Notes

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