

eISSN: 2452-5812
<http://jmh.pucv.cl/>

Received: 19/08/2022
 Accepted: 04/11/2022
 Online-first: 23/11/2022
 Published: 01/01/2023

Review Article

Effect of active video games on cognitive functions in healthy children and adolescents. Systematic review of randomized controlled studies

Efecto de los videojuegos activos sobre las funciones cognitivas de niñas, niños y adolescentes sanos. Revisión sistemática de estudios controlados aleatorizados

Sanchez-Martinez J^{1*}; Tapia-Tapia D¹; Villagra-Ortega A¹; Villegas-Arriagada J¹; Monteiro-Junior R²

Correspondencia ✉

Mg. Javier Sanchez-Martinez
 Escuela de Kinesiología, Universidad Santo Tomás, Viña del Mar, Chile.
sanchez.javier.andre@gmail.com

Abstract

Aims: To examine the effect of active video game interventions (exergames) on cognitive functions in healthy children and adolescents. **Methods:** A systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement, using PubMed, Scopus, and Web of Science databases. The search was restricted to randomized controlled studies evaluating the effect of exergames in a young healthy population on some cognitive variable. **Results:** Five studies met the inclusion criteria. All studies identified an improvement in some cognitive variable after exergame interventions. Only one study implemented an acute protocol of active video games finding a positive effect on cognitive flexibility. Concerning the chronic exergame interventions (range 4–24 weeks), favorable effects on global executive functions and inhibitory control were identified. **Conclusions:** The results of the included studies suggest a favorable acute effect and positive chronic effects of active video game interventions on cognitive variables in healthy children and adolescents. However, these effects appear to be inconclusive given the low number of studies, and the overall methodological quality and risks of bias. Thus, it is necessary to support these findings with future research.

Keywords: brain; cognition; schools; executive function; active-video gaming.

Resumen

Objetivo: Examinar el efecto de intervenciones de videojuegos activos (en inglés: exergames) sobre las funciones cognitivas en niñas, niños y adolescentes sanos. **Métodos:** Se realizó una revisión sistemática siguiendo la norma PRISMA, utilizando las bases de datos PubMed, Scopus y Web of Science. La búsqueda se restringió a estudios aleatorizados y controlados que evalúen el efecto de los exergames en población joven sana sobre alguna variable cognitiva. **Resultados:** Cinco estudios cumplieron los criterios de inclusión. Todos los estudios identificaron una mejora en alguna variable cognitiva luego de la intervención con exergames. Solo un estudio implementó un protocolo agudo de videojuegos activos con un alto compromiso cognitivo, encontrando un efecto positivo sobre la flexibilidad cognitiva. De los estudios con protocolos crónicos de videojuegos activos (rango de 4 a 24 semanas), se identificaron efectos favorables sobre las funciones ejecutivas globales y el control inhibitorio. **Conclusiones:** Los resultados de los estudios incluidos sugieren un efecto agudo favorable y efectos crónicos positivos de intervenciones de videojuegos activos sobre variables cognitivas en niñas, niños y adolescentes sanos. Sin embargo, estos efectos parecen ser inconclusos dada la escasa cantidad de estudios, la calidad metodológica y riesgos de sesgo identificados. De esta manera, es necesario respaldar estos hallazgos con futuras investigaciones.

Palabras clave: cerebro; cognición; escuelas; función ejecutiva; exergames.

Key points

- Only one study has evaluated the acute effect of active video games on cognition in healthy male adolescents, identifying a favorable effect on cognitive flexibility.
- There is evidence, although with limitations, of a chronic effect of exergames on inhibitory control and global executive functions in healthy children and adolescents.
- Considering that the young population accepts and enjoys playing active video games, these could be an alternative to or complement to traditional exercise to improve brain health; however, studies are lacking to support this.

Introduction

Exergames, or active video games, are video games where the person interacts with the console by performing physical activity. Examples of gaming systems that use these types of video games are Xbox Kinect, Nintendo Switch, and PlayStation Move, where the games are usually based on sports or dance activities^{1,2}. These consoles interpret the player's body movements, for example, through cameras or hand controls, to interact with the video game. Thus, exergames increase energy expenditure in preadolescents, ranging from light to vigorous intensities, depending on the video game³.

In children and adolescents, there are known favorable effects of the use of active video games on health. For example, it has been found that they generate a better physiological and psychological response compared to sedentary activities of the same type (such as sedentary video games or watching television)⁴. Additionally, these physiological and psychological responses are similar to those observed in cycling or walking laboratory exercise tests, or physical activity in the field⁴. In addition, it has been identified that active video games increase energy expenditure compared to inactive video games⁵. At the same time, children and adolescents, after interventions through exergames, show improvements in upper limb strength⁶, physical activity level⁷, maximal oxygen consumption⁸, body composition⁹, and body mass index⁸. Thus, this type of video game seems to be a promising tool to promote health in the pediatric population.

In recent years, there has been a growing interest in studying the effect of exergames on cognitive function. For example, in girls and boys with attention deficit hyperactivity disorder, three weekly 30-min active video game sessions per week for eight weeks improved executive function¹⁰. Similarly, in children and adolescents with autism, a favorable effect of exergames on cognitive variables was identified¹¹. On the other hand, a study in children and adolescent cancer survivors did not find an effect after eight weeks of active video games, compared to cognitive training¹². Of note, a recent meta-analysis that included participants with neurological disabilities of all ages identified a positive effect of exergames on attention, executive function, and perception¹³. However, these findings are limited by the high heterogeneity of the results for attention and executive function, and the diversity of participant characteristics and study designs included. In the case of the healthy pediatric population, discrepancies have been found in the effect of exergames on cognitive variables, e.g., inhibitory control, reporting both favorable¹⁴ and null effects¹⁵. Furthermore, to our knowledge, there are no systematic reviews that address the effect of exergames on cognitive variables in healthy children and adolescents.

Thus, although the effect of exergames on cognition has been studied in a young population, reviews have generally focused on participants with neurological disabilities or pathologies^{13,16}. Thus, the aim of this systematic review is to examine the effect of exergame interventions on cognitive functions in apparently healthy children and adolescents.



Methods

This systematic review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines¹⁷.

Search strategy

PubMed, Scopus, and Web of Science databases were searched using the following combination of keywords: (“*active video games*” OR *exergame* OR *exergaming* OR “*video game*” OR “*computer game*” OR “*virtual reality*” OR “*Nintendo Wii*” OR “*dance dance revolution*” OR “*computer interaction*” OR *kinetic*) AND (*children* OR *teenagers* OR *adolescent* OR *young*) AND (*cognition* OR “*cognitive functions*” OR “*cognitive development*” OR “*executive functions*”). The search was conducted with no date limit until August 2021.

Study selection criteria

Eligible studies had to meet the following Participants, Intervention, Comparator, Outcomes, and Study Design (PICOS) criteria: i) Participants: Healthy children or adolescents, without chronic pathologies or cognitive impairment; ii) Intervention: Acute or chronic exposure to exergames; iii) Comparator: Studies that in addition to the intervention group contain groups that do not perform exergames; iv) Outcomes: Present pre- and post-intervention measurements of some cognitive component, indicating the effect or result; and v) Study Design: Randomized controlled trials. Studies published in English and Spanish were considered.

Search, filtering, and selection of studies

The search in each database, using the combination of keywords previously described, was performed simultaneously by four reviewers (A.V.O., J.V.A., D.T.T., J.S.M.). The search results were exported and organized in the Zotero bibliographic manager. Subsequently, the process of filtering and selection of the studies was performed, independent and blinded, by three reviewers (A.V.O., J.V.A., D.T.T.). Disagreements were resolved by a fourth reviewer (J.S.M.). The study selection process began with an initial filter in which the articles were analyzed according to title and abstract. Subsequently, the studies that passed the first filter were analyzed by full text. The reason for exclusion of the studies reviewed by full text was made explicit. Gray literature was excluded during the filtering and article selection process. References of studies that met the inclusion criteria, as well as systematic reviews related to exergames and cognition, were analyzed for possible eligible studies.

Data extraction and synthesis

Three reviewers (A.V.O., J.V.A., D.T.T.), independent and blinded, extracted the following information from the included studies: author, year of publication, study design, participant characteristics (country of origin, age, number of participants, and sex), exergame intervention characteristics (exergame type, session duration, session frequency, intervention duration, intensity), comparator group characteristics (indications or control group exposure), and outcomes (cognitive function assessed, instrument used, intervention results). Disagreements were resolved by a fourth reviewer (J.S.M.). The information collected was synthesized in a descriptive table, sorting the studies according to the duration of the intervention.

Assessment of methodological quality and risk of bias

Three reviewers (A.V.O., J.V.A., D.T.T.), independent and blinded, assessed the methodological quality of the included studies using the ten-point PEDro scale¹⁸. Disagreements were resolved by a fourth reviewer (J.S.M.). Methodological quality was categorized as high when the study scored six or higher, and as low for articles scoring five or lower¹⁹.

The risk of bias assessment was performed by three reviewers (A.V.O., J.V.A., D.T.T.), independent and blinded, using the Cochrane Bias Assessment Tool for Randomized Trials (RoB 2)²⁰. Disagreements in the assessment were resolved by a fourth reviewer (J.S.M.). This tool assesses the risk of bias in five domains: i) bias from the randomization process; ii) bias to deviations from intended interventions; iii) bias from missing outcome data; iv) bias in outcome measurement; and v) bias from selection of the reported outcome. In addition, an overall risk of bias is derived based on the results of these five dimensions. This tool categorizes the risk of bias into three levels: i) low risk of bias; ii) some risk of bias concerns; and iii) high risk of bias.

Effect size

The effect size for each cognitive variable in each study was calculated using Cohen's d (difference between two means divided by a pooled standard deviation for two independent variables), considering the pre and post data of the intervention and control groups. WebPlotDigitizer software was used to extract and estimate data from figures when the article did not present numerical values²¹. When the article presented results as median, minimum, and maximum, the mean and standard deviation were estimated²². In the case of not having data from the control group, the intragroup experimental effect size was calculated. Positive values of the effect size express benefits on the cognitive variable in favor of the experimental group. The cutoffs 0.1, 0.3, 0.5, 0.7, and 0.9 were used for small, moderate, large, very large, and extremely large effect sizes, respectively²³.

Results

Search, filtering, and selection of studies

The process of searching, filtering and selection of studies is summarized in the flow diagram illustrated in Figure 1. By applying the search strategy in the declared databases, 3,748 articles were identified, and after eliminating duplicates, 2,898 records were analyzed according to title and abstract. After applying this initial filter, 20 studies were analyzed according to full text. The reason for exclusion of the studies analyzed by full text is described in Figure 1. Finally, five studies met the inclusion criteria and were included in the present systematic review^{14,15,24,25,26}, comprising nine reports of the included studies considering the experimental groups with identified exergames.

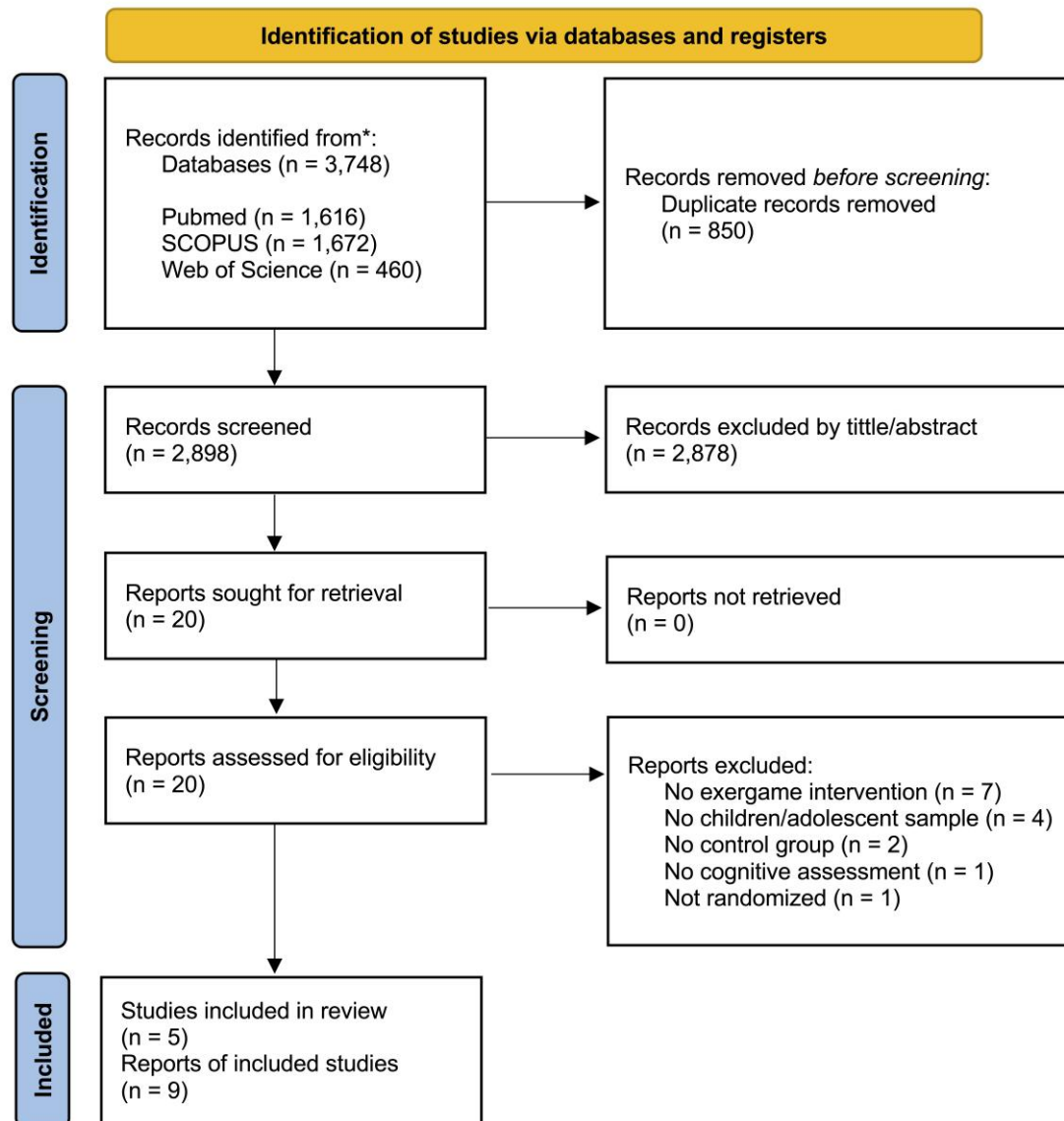


Figure 1. Flow diagram of the search and filter process.

Characteristics of the included studies

The characteristics of the selected studies are summarized in Table 1. Regarding the age of the participants, three of the five included studies were in the age range between 10–19 years^{15,25,26}, while two studies were between 7–9 years of age^{14,24}. Regarding the sex of the participants, only one study included exclusively males¹⁵, while the remaining studies included both males and females^{14,24,25,26}. Regarding the characteristics of the interventions, only one study evaluated the acute effect of active video games¹⁵, while the rest involved interventions of four weeks^{24,25}, ten-weeks²⁶, and 24 weeks¹⁴ of duration. The time range of the exergame sessions was from 10 minutes²⁴ to 60 minutes²⁵, while the frequency of weekly sessions of the chronic interventions ranged from one^{14,26} to five days^{24,25}. The most commonly used platform for exergaming was Xbox Kinect^{14,15,24} followed by Nintendo Wii^{25,26}. Regarding the cognitive variable evaluated, most of the studies (3/5) used the Delis–Kaplan Executive Function System (D-KEFS) to measure executive functions, while the rest evaluated the effect of active video games on inhibitory control using the Go/No-Go test or Simon task.

**Table 1.** Characteristics of selected studies that evaluated the effect of exergames on cognition in healthy children and adolescents.

Study	Participants (Country, age, n, gender)	Intervention and comparator	Structure of the intervention	Cognitive variable (instrument)	Intervention outcome (Reported by study)	Effect size (Cohen's d)
Benzing et al., 2016 ¹⁵	Switzerland, 13–16 y, n = 65, male	E1: Shape Up game, with high cognitive engagement (Xbox Kinect)	E1: In the game, new movement sequences are imitated and learned, similar to aerobics. 15 min. Self- determined intensity.	Executive functions (D-KEFS)	<u>Fluency:</u> NS	$d_{E1 \text{ vs } C} =$ –0.20
		E2: Your Shape Fitness Evolved 2012 game, with low cognitive engagement (Xbox Kinect)			<u>Inhibition:</u> NS	$d_{E2 \text{ vs } C} =$ –0.07
		C: Watch video on computer			<u>Cognitive flexibility:</u> E1↑, E1>E2=C	$d_{E1 \text{ vs } C} =$ 0.53 $d_{E2 \text{ vs } C} =$ 0.28
Layne et al., 2020 ²⁴	United States, 8–9 y, n = 40, 77.5% male	E: FitNexx 1.0 (Xbox Kinect)	E: Game involving walking, running, and jumping in place. 10 min x 5d/week x 4 weeks. Moderate– vigorous intensity	Inhibitory control (Go/No-Go test)	<u>Reaction time:</u> E<C	$d_{E \text{ vs } C} =$ 1.55
		C: Normal activities			<u>Response inhibition control:</u> E>C	$d_{E \text{ vs } C} =$ 1.21
Flynn et al., 2014 ²⁵	United States, 10–16 y, n = 70, 52.9% male	E1: Wii Fit game (Nintendo Wii), highly active	E1: Aerobic and balance games. 60 min x 5d/week x 4 weeks. Intensity: NR	Executive functions (D-KEFS)	E1: ↑	$d_{E \text{ post-pre}} =$ 0.58
		E2: Boom Blox game (Nintendo Wii), less active	E2: Puzzle action game, less active than E1. 60 min x 5d/week x 4 weeks. Intensity: NR		E2: NS	No data
		C: No game			C: NS	No data
Staiano et al., 2012 ²⁶	United States, 15–19 y, n = 54, 42.6% male	E1: EA Sports game (Nintendo Wii) in competitive mode	Cardio routines, upper and lower limb strength training, and sports games. 30 min x 1d/week x 10 weeks. Intensity: NR	Executive functions (D-KEFS)	E1: ↑	$d_{E1 \text{ vs } C} =$ 0.80
		E2: EA Sports game (Nintendo Wii) in cooperative mode			E1>E2=C	$d_{E2 \text{ vs } C} =$ 0.27
		C: No game				

Table 1. Cont.

Šlosar et al., 2021 ¹⁴	Slovenia, 7–9 y, n = 63, 57.1% male	E1: 1 tennis session + 1 Virtua Tennis 4 game session (Xbox Kinect)	E1: 60 min (tennis) + 20 min (exergame) x 1d/week x 24 weeks. Intensity: NR	Inhibitory control (Simon task)	Response accuracy: NS	No data
		E2: 2 tennis sessions + 2 Virtua Tennis 4 game sessions (Xbox Kinect)	E2: 60 min (tennis) + 20 min (exergame) x 2d/week x 24 weeks. Intensity: NR		Reaction time on congruent trials: E1<C1, E2<C2	d _{E1} vs C1 = 0.21
		C1: 1 tennis session per week			Reaction time on incongruent trials: E1<C1, E2<C2	d _{E2} vs C2 = 0.06
		C2: 2 tennis sessions per week				d _{E1} vs C1 = 0.18
						d _{E2} vs C2 = 0.59

Notes: C: Control group; d: Cohen's d; D-KEFS: Delis–Kaplan Executive Function System; E: Experimental group; NR: Not reported; NS: Not significant differences; ↑: Significant increase compared to baseline; <: Result significantly lower than; >: Result significantly higher than; =: Result equal to.

Effect of exergames on cognition in a young healthy population

First, on the results of the studies that evaluated the effect of active video games on executive functions, favorable findings were found. On the one hand, two studies found a favorable effect of exergames on global executive function^{25,26}. From these studies, we identified a large effect in a group exposed to exergames ($d_{E \text{ post-pre}} = 0.58$)²⁵ and a very large effect compared to the control group ($d_{E1 \text{ vs } C} = 0.80$)²⁶. In more detail, only the competitively applied exergame, as opposed to the cooperative one, increased executive function performance²⁶. On the other hand, another study identified that, acutely, active video games applied with higher cognitive engagement, as opposed to active video games with lower cognitive engagement and the control group, increased the cognitive flexibility component of executive functions ($d_{E1 \text{ vs } C} = 0.41$, moderate effect), but not the fluency and inhibition components¹⁵.

Secondly, the two studies that evaluated the chronic effect of active video games on inhibitory control found a positive effect. On the one hand, the study by Layne et al. identified that four weeks of 10 min of exergames, five days a week, improves performance in the Go/No-Go test, decreasing reaction time ($d_{E \text{ vs } C} = 1.55$, extremely large effect) and enhancing inhibitory response control ($d_{E \text{ vs } C} = 1.21$, extremely large effect)²⁴. On the other hand, the study by Šlosar et al. found that one and two weekly sessions of exergames in addition to tennis training for six months decreased reaction time in congruent (small and trivial effects, respectively) and incongruent tasks of inhibitory control (small and large effects, respectively), although with no difference in response accuracy¹⁴.

Assessment of methodological quality and risk of bias

The result of the evaluation of the methodological quality of the included studies is described in Table 2. The average PEDro scale score was 5.0 ± 1.0 points. Three of the five included studies had a low methodological quality^{15,24,25}. The remaining studies were of high quality, although at the lower limit^{14,26}. The criterion which all the studies met was randomization, while the items that none met were concealed allocation, and blinding of therapists and assessors.

Table 2. Methodological quality scores of the included studies according to PEDro criteria.

Criteria	Benzing et al., 2016 ¹⁵	Layne et al., 2020 ²⁴	Flynn et al., 2014 ²⁵	Staiano et al., 2012 ²⁶	Slosar et al., 2021 ¹⁴
Eligibility	Yes	No	Yes	Yes	Yes
1. Random allocation	1	1	1	1	1
2. Concealed allocation	0	0	0	0	0
3. Baseline comparability	0	1	1	1	1
4. Blind subjects	0	0	0	0	1
5. Blind therapists	0	0	0	0	0
6. Blind assessors	0	0	0	0	0
7. Adequate follow-up	1	0	1	1	0
8. Intention-to-treat-analysis	1	1	0	1	1
9. Between-group comparison	1	1	0	1	1
10. Point estimated variability	1	0	1	1	1
Score	5/10	4/10	4/10	6/10	6/10
Quality	Low	Low	Low	High	High

Figure 2 summarizes the results of the risk of bias assessment of the included studies. In relation to overall bias, two studies presented high risk of bias^{14,25}, two studies showed some concerns^{24,26}, and only one study achieved a low overall risk of bias, as well as in all domains¹⁵. In particular, all studies achieved a low risk in the domains of missing outcome data and outcome measurement^{14,15,24,25,26}.

In relation to the bias of the randomization process, four of the five studies showed some concerns^{14,24,25,26}, mainly for not making the randomization mechanism explicit. Only one study had a high risk of bias in the deviation from the intended interventions²⁵ and two studies a high risk of bias in the selection of the reported outcome^{14,25}.

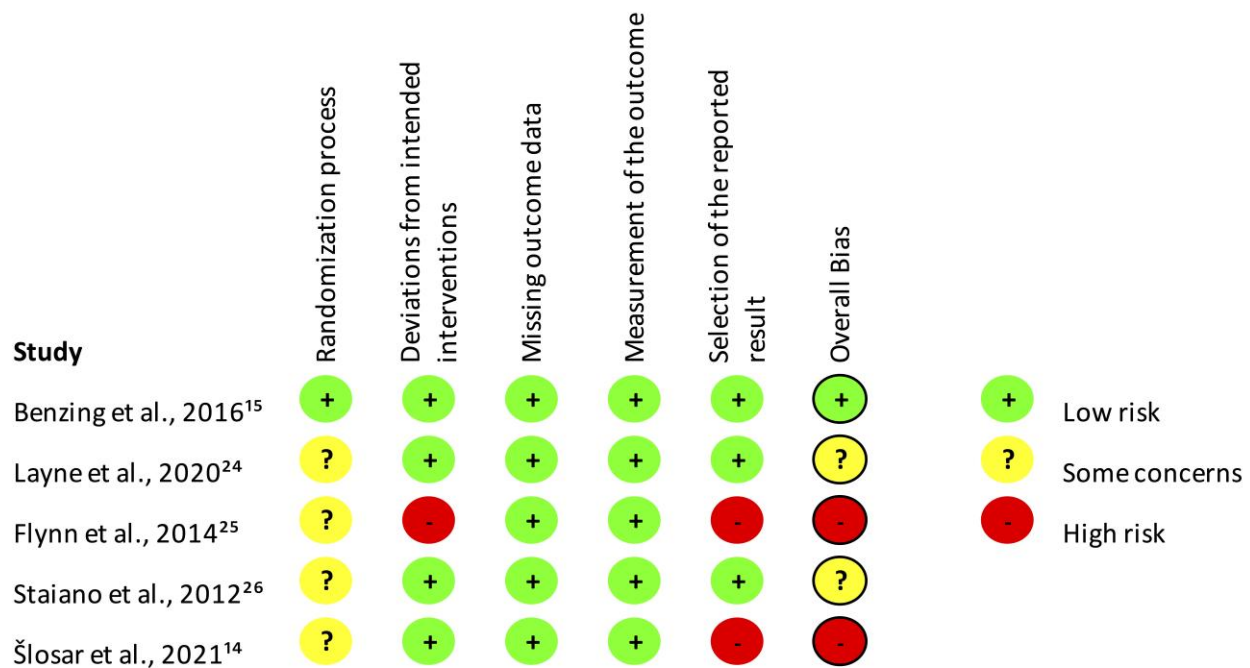


Figure 2. Risk of bias of included studies.

Discussion

The aim of this review was to investigate the literature on the effect of exergames on cognitive functions in healthy children and adolescents. Based on the five studies that met the inclusion criteria, we identified that there is evidence, albeit with limitations, of a favorable acute effect after an exergame intervention on cognitive flexibility, and a chronic effect of exergames on inhibitory control and global executive functions.

The effects of exergames on cognition in healthy children and adolescents appear to be similar to those reported in systematic reviews that included children with neurological disabilities¹³ and healthy adolescents²⁷. However, the comparison of the findings of these studies with our results is limited, because in one review only two of the 13 included studies were in a young population¹³, while in the other review only one of the 17 included studies was in adolescents²⁷. We did not identify other systematic reviews including children and adolescents that evaluate the effect of exergames on any of the cognitive variables we identified (e.g., executive function). Therefore, it is difficult to compare our findings with previous reviews, considering the limited number of studies on the subject.

The effect of exergames on cognition would be justified based on the aerobic exercise and the cognitive demand of this intervention. The acute and chronic effects of aerobic exercise on executive functions and attention in preadolescents is well known²⁸. Moreover, sports or curricular exercise classes improve general executive functions and inhibitory control²⁹. Several mechanisms have been proposed to support cognitive improvements after exercise, such as increased cerebral vascularization and blood flow, increased neurotrophic factors, gray matter, and functional connectivity³⁰. In particular, postexercise improvements in executive functions, such as inhibitory control and cognitive flexibility, are related to an increase in volume and activation of the prefrontal area^{31,32,33,34}. In addition, a synergistic effect between exercise and cognitive training on cognitive functions or dual tasks has been reported^{35,36}. Studies in older

adults have found that interventions with active video games improve the performance of executive functions and global cognition, as well as a greater efficiency of prefrontal area activation^{37,38}. However, to our knowledge there are no studies that evaluate the effect of exergames on brain structure and function in children and adolescents, so future studies should elucidate this unknown.

Some characteristics of exergame interventions appear to impact cognition in a young healthy population. For example, the included studies comparing different exergame protocols found that the more cognitively engaged¹⁵, more physically active²⁵ and a competitive modality²⁶ showed greater cognitive improvements in healthy children and adolescents. Furthermore, the study by Šlosar et al. identified that virtual tennis exergame interventions, in addition to traditional tennis training, improved inhibitory control compared to tennis-only sessions¹⁴. This suggests that adding exergame sessions could enhance the effect of traditional sports or exercise interventions. Thus, considering the synergistic effect between exercise and cognitively demanding activities, exergames seem to be an alternative to stimulate cognition in healthy children and adolescents. However, there are characteristics of exergame interventions, such as exercise intensity, where dosage is not clear, because none of the included studies objectively dosed or monitored exercise intensity. Some meta-analyses have found exercise intensity to be a moderator of cognitive effects^{39,40}. Therefore, future studies should objectify and analyze the role of exercise intensity on cognition in exergame interventions. Finally, the limited number of studies published on this topic should be considered, so more evidence is needed to elucidate the dose-response of exergames, and which characteristics of the intervention are the most appropriate to enhance the effect on cognition.

Considering the findings of exergaming interventions on cognition in healthy children and adolescents, this intervention could have a transfer to the school context and academic performance. For example, one study identified that in adolescents with developmental coordination disorders, eight weeks of gaming using a Wii Fit console (30-minute sessions, three times per week) after school or at recess improved executive functions compared to the control group⁴¹. Similarly, four weeks of active video games on weekends increased executive functions in preschoolers compared to traditional physical activity⁴². Regarding academics, it has been identified that the application of exergames during the school year improves academic performance in mathematics⁴³. Finally, the high degree of acceptance and enjoyment reported when using exergames in children and adolescents should be considered^{44,45}, as well as the favorable effect on the level of physical activity⁴⁴ and physical capacity⁴⁶, taking into account that this population has low levels of physical activity^{47,48}, and that they perceived a greater decrease during the COVID-19 pandemic⁴⁹. Thus, although the evidence is scarce, it seems that exergames could be considered as a complementary activity to physical education classes, as well as at home, to improve cognition, academic performance, and physical activity levels.

The included studies presented, in general, a low methodological quality and a risk of bias with considerations or high, limiting the conclusions from the results. First, the nature of the design of the included studies should be considered, making it impossible to achieve a higher methodological quality score. For example, compliance with blinding of both participants and therapists is difficult in these types of field studies under natural conditions, given the knowledge of the intervention applied. However, to improve methodological quality, future studies should strive to meet criteria such as the presentation of participants' results, statistical comparison, and variability statistics, among others. On the other hand, because this review included exclusively randomized trials, this criterion was met by all studies on the PEDro scale. However, when assessing the bias of the randomization process, it was identified that most of the studies did not make the procedure explicit, which raises some concerns. All the above, added to the other domains of methodological quality and risk of bias, should be considered when interpreting the results of the studies and the conclusions generated in the present review, as it would also help future studies on this subject to improve the quality of the evidence.

Limitations and Strengths

On the one hand, the present review has as a strength the application of the recommendations of the PRISMA statement for reporting the systematic review. In addition, it is noteworthy that the processes of filtering, selection, data extraction, assessment of methodological quality and risk of bias were performed by three reviewers, independent and blinded, and disagreements resolved by a fourth reviewer. On the other hand, this systematic review is not without limitations. One of them is the number of databases included, which was limited by the availability of access. It is known that the number of databases can modify the conclusions of reviews and meta-analyses⁵⁰. Therefore, the conclusions of this review should be interpreted considering this limitation. Another limitation was the impossibility of performing a meta-analysis due to the limited number of cognitive variables in common among the included studies.

In addition to the above, the variability of tools used to assess different cognitive variables should be considered, which could limit the comparison of findings between studies and conclusions. Furthermore, the limited number of included studies limits the interpretation of the characteristics of the exergame intervention (intensity, duration, among others) on cognition in this population. Thus, future studies comparing the effect of different exergame protocols (duration, intensity, modality, etc.) on cognition in healthy children and adolescents are needed to elucidate the dose-response of this intervention. To complement the above, future studies should evaluate the effect of exergames on learning, school performance, and behavior, to consider their application in the educational context. Finally, considering the methodological quality and risk of bias identified in the included studies, the results of this review should be interpreted with caution. Therefore, future studies on this topic should consider increasing the methodological quality and decreasing the risk of bias, based on the domains evaluated in this review, to obtain more reliable conclusions on the effect of active video games on cognition in healthy children and adolescents.

Conclusions

This systematic review identified a limited number of studies evaluating the effect of exergames on cognition in healthy children and adolescents. Based on these studies, there is evidence that exergames generate favorable acute and chronic effects on executive functions, although in general the studies present a low methodological quality and high risk of bias or with considerations. We recommend increasing the methodological quality of future research evaluating the effect of exergames on cognitive variables in a young population to corroborate the findings.

References

1. Ofori EK, Subramaniam S, Wang S, Bhatt T. Kinematic analysis of dance-based exergaming: effect of song pace on center of mass and joint mobility. *J Phys Ther Sci.* 2019;31(9):708-716. DOI:10.1589/jpts.31.708
2. Sato T, Shimizu K, Shiko Y, et al. Effects of Nintendo Ring Fit Adventure exergame on pain and psychological factors in patients with chronic low back pain. *Games Health J.* 2021;10(3):158-164. DOI:10.1089/g4h.2020.0180
3. Hwang J, Lee IM, Fernandez AM, Hillman CH, Lu AS. Exploring energy expenditure and body movement of exergaming in children of different weight status. *Pediatr Exerc Sci.* 2019;31(4):438-447. DOI:10.1123/pes.2019-0006

4. Gao Z, Chen S, Pasco D, Pope Z. A meta-analysis of active video games on health outcomes among children and adolescents: A meta-analysis of active video games. *Obes Rev.* 2015;16(9):783-794. DOI:10.1111/obr.12287
5. Leatherdale S. Energy expenditure while playing active and inactive video games. *Am J Health Behav.* 2010;34(1). DOI:10.5993/AJHB.34.1.4
6. Viana RB, Oliveira VN, Dankel SJ, et al. The effects of exergames on muscle strength: A systematic review and meta-analysis. *Scand J Med Sci Sports.* 2021;31(8):1592-1611. DOI:10.1111/sms.13964
7. Williams WM, Ayres CG. Can active video games improve physical activity in adolescents? A review of RCT. *Int J Environ Res Public Health.* 2020;17(2):669. DOI:10.3390/ijerph17020669
8. Comeran-Chueca C, Marin-Puyalto J, Matute-Llorente A, Vicente-Rodriguez G, Casajus JA, Gonzalez-Aguero A. The effects of active video games on health-related physical fitness and motor competence in children and adolescents with healthy weight: A systematic review and meta-analysis. *Int J Environ Res Public Health.* 2021;18(13):6965. DOI:10.3390/ijerph18136965
9. Gao Z, Zeng N, McDonough DJ, Su X. A systematic review of active video games on youth's body composition and physical activity. *Int J Sports Med.* 2020;41(09):561-573. DOI:10.1055/a-1152-4959
10. Benzing V, Schmidt M. The effect of exergaming on executive functions in children with ADHD: A randomized clinical trial. *Scand J Med Sci Sports.* 2019;29(8):1243-1253. DOI:10.1111/sms.13446
11. Anderson-Hanley C, Tureck, Schneiderman. Autism and exergaming: effects on repetitive behaviors and cognition. *Psychol Res Behav Manag.* 2011:129. DOI:10.2147/PRBM.S24016
12. Benzing V, Spitzhüttl J, Siegwart V, et al. Effects of cognitive training and exergaming in pediatric cancer survivors - A randomized clinical trial. *Med Sci Sports Exerc.* 2020;52(11):2293-2302. DOI:10.1249/MSS.0000000000002386
13. Mura G, Carta MG, Sancassiani F, Machado S, Prosperini L. Active exergames to improve cognitive functioning in neurological disabilities: a systematic review and meta-analysis. *Eur J Phys Rehabil Med.* 2018;54(3). DOI:10.23736/S1973-9087.17.04680-9
14. Šlosar L, de Bruin ED, Fontes EB, et al. Additional exergames to regular tennis training improves cognitive-motor functions of children but may temporarily affect tennis technique: A single-blind randomized controlled trial. *Front Psychol.* 2021;12:611382. DOI:10.3389/fpsyg.2021.611382
15. Benzing V, Heinks T, Eggenberger N, Schmidt M. Acute cognitively engaging exergame-based physical activity enhances executive functions in adolescents. *PLOS ONE.* 2016;11(12):e0167501. DOI:10.1371/journal.pone.0167501
16. Lima JL, Axt G, Teixeira DS, et al. Exergames for children and adolescents with autism spectrum disorder: An overview. *Clin Pract Epidemiol Ment Health.* 2020;16(1):1-6. DOI:10.2174/1745017902016010001
17. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Syst Rev.* 2021;10(1):89. DOI:10.1186/s13643-021-01626-4
18. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother.* 2009;55(2):129-133. DOI:10.1016/S0004-9514(09)70043-1
19. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther.* 2003;83(8):713-721. DOI:10.1093/ptj/83.8.713
20. Higgins JPT, Altman DG, Gotzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ.* 2011;343:d5928. DOI:10.1136/bmj.d5928
21. Burda BU, O'Connor EA, Webber EM, Redmond N, Perdue LA. Estimating data from figures with a Web-based program: Considerations for a systematic review. *Res Synth Methods.* 2017;8(3):258-262. DOI:10.1002/jrsm.1232

22. Hozo SP, Djulbegovic B, Hozo I. Estimating the mean and variance from the median, range, and the size of a sample. *BMC Med Res Methodol.* 2005;5(1):13. DOI:10.1186/1471-2288-5-13
23. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc.* 2009;41(1):3-12. DOI:10.1249/MSS.0b013e31818cb278
24. Layne T, Yli-Piipari S, Knox T. Physical activity break program to improve elementary students' executive function and mathematics performance. *Educ 3-13.* 2021;49(5):583-591. DOI:10.1080/03004279.2020.1746820
25. Flynn RM, Richert RA, Staiano AE, Wartella E, Calvert SL. Effects of exergame play on EF in children and adolescents at a summer camp for low income youth. *J Educ Dev Psychol.* 2014;4(1):p209. DOI:10.5539/jedp.v4n1p209
26. Staiano AE, Abraham AA, Calvert SL. Competitive versus cooperative exergame play for African American adolescents' executive function skills: Short-term effects in a long-term training intervention. *Dev Psychol.* 2012;48(2):337-342. DOI:10.1037/a0026938
27. Stanmore E, Stubbs B, Vancampfort D, de Bruin ED, Firth J. The effect of active video games on cognitive functioning in clinical and non-clinical populations: A meta-analysis of randomized controlled trials. *Neurosci Biobehav Rev.* 2017;78:34-43. DOI:10.1016/j.neubiorev.2017.04.011
28. de Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E. Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *J Sci Med Sport.* 2018;21(5):501-507. DOI:10.1016/j.jsams.2017.09.595
29. Xue Y, Yang Y, Huang T. Effects of chronic exercise interventions on executive function among children and adolescents: a systematic review with meta-analysis. *Br J Sports Med.* 2019;53(22):1397-1404. DOI:10.1136/bjsports-2018-099825
30. Hötting K, Röder B. Beneficial effects of physical exercise on neuroplasticity and cognition. *Neurosci Biobehav Rev.* 2013;37(9):2243-2257. DOI:10.1016/j.neubiorev.2013.04.005
31. Damrongthai C, Kuwamizu R, Suwabe K, et al. Benefit of human moderate running boosting mood and executive function coinciding with bilateral prefrontal activation. *Sci Rep.* 2021;11(1):22657. DOI:10.1038/s41598-021-01654-z
32. Fujihara H, Megumi A, Yasumura A. The acute effect of moderate-intensity exercise on inhibitory control and activation of prefrontal cortex in younger and older adults. *Exp Brain Res.* 2021;239(6):1765-1778. DOI:10.1007/s00221-021-06086-9
33. Soshi T, Andersson M, Kawagoe T, et al. Prefrontal plasticity after a 3-month exercise intervention in older adults relates to enhanced cognitive performance. *Cereb Cortex.* 2021;31(10):4501-4517. DOI:10.1093/cercor/bhab102
34. Brockett AT, LaMarca EA, Gould E. Physical exercise enhances cognitive flexibility as well as astrocytic and synaptic markers in the medial prefrontal cortex. *PLOS ONE.* 2015;10(5):e0124859. DOI:10.1371/journal.pone.0124859
35. Eggenberger P, Schumacher V, Angst M, Theill N, de Bruin ED. Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clin Interv Aging.* 2015;10:1335-1349. DOI:10.2147/CIA.S87732
36. Bherer L, Gagnon C, Langeard A, et al. Synergistic Effects of cognitive training and physical exercise on dual-task performance in older adults. *J Gerontol Ser B.* 2021;76(8):1533-1541. DOI:10.1093/geronb/gbaa124

37. Liao YY, Chen IH, Hsu WC, Tseng HY, Wang RY. Effect of exergaming versus combined exercise on cognitive function and brain activation in frail older adults: A randomised controlled trial. *Ann Phys Rehabil Med*. 2021;64(5):101492. DOI:10.1016/j.rehab.2021.101492
38. Schättin A, Arner R, Gennaro F, de Bruin ED. Adaptations of prefrontal brain activity, executive functions, and gait in healthy elderly following exergame and balance training: A randomized-controlled study. *Front Aging Neurosci*. 2016;8. DOI:10.3389/fnagi.2016.00278
39. Liang X, Li R, Wong SHS, Sum RKW, Sit CHP. The impact of exercise interventions concerning executive functions of children and adolescents with attention-deficit/hyperactive disorder: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. 2021;18(1):68. DOI:10.1186/s12966-021-01135-6
40. Northey JM, Cherbuin N, Pumpa KL, Smee DJ, Rattray B. Exercise interventions for cognitive function in adults older than 50: a systematic review with meta-analysis. *Br J Sports Med*. 2018;52(3):154-160. DOI:10.1136/bjsports-2016-096587
41. Hashemi A, Khodaverdi Z, Zamani MH. Effect of Wii Fit training on visual perception and executive function in boys with developmental coordination disorders: A randomized controlled trial. *Res Dev Disabil*. 2022;124:104196. DOI:10.1016/j.ridd.2022.104196
42. Liu ZM, Chen CQ, Fan XL, Lin CC, Ye XD. Usability and effects of a combined physical and cognitive intervention based on active video games for preschool children. *Int J Environ Res Public Health*. 2022;19(12):7420. DOI:10.3390/ijerph19127420
43. Gao Z, Hannan P, Xiang P, Stodden DF, Valdez VE. Video game-based exercise, latino children's physical health, and academic achievement. *Am J Prev Med*. 2013;44(3):S240-S246. DOI:10.1016/j.amepre.2012.11.023
44. Staiano AE, Beyl RA, Guan W, Hendrick CA, Hsia DS, Newton RL. Home-based exergaming among children with overweight and obesity: a randomized clinical trial: Home exergaming in children with obesity. *Pediatr Obes*. 2018;13(11):724-733. DOI:10.1111/ijpo.12438
45. Graves LEF, Ridgers ND, Williams K, Stratton G, Atkinson G, Cable NT. The physiological cost and enjoyment of wii fit in adolescents, young adults, and older adults. *J Phys Act Health*. 2010;7(3):393-401. DOI:10.1123/jpah.7.3.393
46. Smits-Engelsman B, Bonney E, Ferguson G. Effects of graded exergames on fitness performance in elementary school children with developmental coordination disorder. *Front Sports Act Living*. 2021;3:653851. DOI:10.3389/fspor.2021.653851
47. Aubert S, Barnes JD, Abdeta C, et al. Global matrix 3.0 physical activity report card grades for children and youth: Results and analysis from 49 countries. *J Phys Act Health*. 2018;15(s2):S251-S273. DOI:10.1123/jpah.2018-0472
48. Erazo-Díaz N, Rojas-Cisterna C, Poblete-Donoso M, et al. Intensidad y gasto energético de la actividad física durante la jornada escolar en niñas con y sin trastorno por déficit de atención e hiperactividad. *J Mov Health*. 2022;19(1). DOI:10.5027/jmh-Vol19-Issue1(2022)art151
49. Da Cunha GDOK, Da Cunha GB, Hartwig TW, Bergmann GG. Association between changes in physical activity levels and depressive symptoms in high school students during the COVID-19 pandemic. *J Mov Health*. 2022;19(1). DOI:10.5027/jmh-Vol19-Issue1(2022)art145
50. Harari MB, Parola HR, Hartwell CJ, Riegelman A. Literature searches in systematic reviews and meta-analyses: A review, evaluation, and recommendations. *J Vocat Behav*. 2020;118:103377. DOI:10.1016/j.jvb.2020.103377

Affiliations

¹Escuela de Kinesiología, Facultad de Salud, Universidad Santo Tomás, Viña del Mar, Chile.

²Programa de Pós-Graduação em Ciências da Saúde, Universidade Estadual de Montes Claros, Montes Claros, MG, Brasil.

Author Contributions

Design and drafting of the manuscript: J.S.M; Literature search: A.T.T, A.V.O, J.V.A; Data collection: J.S.M, A.T.T, A.V.O, J.V.A; Analysis and interpretation of data: J.S.M; Critical revision of the manuscript: J.S.M, R.M.J; Approval of the final version: J.S.M, R.M.J, A.T.T, A.V.O, J.V.A.

Conflict of interest

The authors have no conflict of interest to declare.



Copyright © The Author(s). This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA 4.0).
<https://creativecommons.org/licenses/by-sa/4.0/>