Research in Autism Spectrum Disorders 94 (2022) 101953

Contents lists available at ScienceDirect

Research in Autism Spectrum Disorders

journal homepage: www.elsevier.com/locate/rasd

The non-fitness-related benefits of exergames for young individuals diagnosed with autism spectrum disorder: A systematic review

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ARTICLE INFO

Keywords:
Autism Spectrum Disorder
Young
Communication
Social Development
Physical Activity
Exergames

ABSTRACT

Background: Autism Spectrum Disorder (ASD) is a common neurodevelopmental condition characterized by social-communication deficits and is often accompanied by an array of autism-specific traits, including cognitive and motor differences. Research has begun to investigate the utility of exergames (virtual exercise games) for combating some of the functionally impairing facets of ASD. However, no review to date has investigated the positive effects of exergaming for young autistic individuals, exclusive of their effects on fitness-related/health-related outcomes.
Methods: We systematically reviewed the literature for articles published between 1990 and 2020, which aimed to examine the effectiveness of exergames for targeting some of the facets observed in autistic children, exclusive of physical fitness-related outcomes.
Results: Out of 193 relevant articles, 10 met the inclusion criteria. Some studies showed initial beneficial effects of exergaming for executive function and motor skills, however more work is needed to examine the beneficial effects of exergaming for social development in young autistic individuals.
Conclusion: The present review suggests the potential use of exergaming for enhancing some functions in ASD and future research is needed to expand the use of exergames for supporting social-communication skills. Furthermore, additional studies using rigorous research designs are needed to draw stronger conclusions about the effects of exergames for the young autistic population.

1. Introduction

1.1. Autism

Autism Spectrum Disorder (ASD)[2] is a long-term neurodevelopmental condition accompanied by a markedly focused repertoire of

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[2] We, as authors, note the differing opinions for use of preferred language within the autistic community with regards to term ‘Autism Spectrum Disorder’ versus ‘Autism Spectrum Condition’. However, we have decided to implement the term Autism Spectrum Disorder due to its continued use by the National Health Service (NHS, 2019).

https://doi.org/10.1016/j.rasd.2022.101953
Received 24 March 2021; Received in revised form 25 February 2022; Accepted 11 March 2022
Available online 24 March 2022
1750-9467/

activities and passionate interests and is diagnosed by profound social-communication challenges and difficulties with verbal and non-verbal communication (American Psychiatric Association, 2013; Bottema-Beutel, Kapp, Lester, Sasson, & Hand, 2021). The direct cause, or etiology, of ASD is unknown. However, it is thought to derive from a multitude of genetic, biological, and environmental factors; suggesting a complex interplay between genes and the environment resulting in atypical development (Cheroni, Caporale, & Testa, 2020). Currently, the World Health Organization (WHO) proposes that 1 in every 160 children has an ASD diagnosis worldwide (Elsabbagh et al., 2012; WHO, 2019). However, this rate has been increasing over time and currently stands at 1 in every 100 children in the United Kingdom (Taylor, Jick, & MacLaughlin, 2013), and 1 in every 54 children in the United States of America (CDC, 2020; Maenner, 2020).

Although it is most commonly understood that individuals who have a diagnosis of ASD experience challenges with social communication and interactions, alongside repetitive or restricted behaviors, it is increasingly recognized that autistic individuals show reduced motor proficiencies and executive dysfunction. The available literature suggests that between 60% and 80% of autistic children exhibit some kind of motor challenge (Dziuk et al., 2007; Fournier, Hass, Naik, Lodha, & Cauraugh, 2010; Gargot et al., 2022; Ming, Brimacombe, & Wagner, 2007). A recent study, including data from 11,814 autistic children, reported that the proportion of autistic children at risk of a motor impairment was very high at 86.9% (Bhat, 2020). However only 31.6% of these children were receiving physical therapy services. In comparison to their typically developing (TD) peers, those with a diagnosis of ASD are more likely to express difficulties with balance, gait, postural stability, movement speed and joint flexibility (Ghaziuddin & Butler, 1998; Jansiewicz et al., 2006; Minshew, Sung, Jones, & Furman, 2004, and see Hudry, Chetcuti, & Hocking, 2020 and Lim, Partridge, Girdler, & Morris, 2017 for reviews). For example, using the Henderson Test of Motor Impairment (Lam & Henderson, 1987), Manjiviona and Prior (1995) reported impaired movement in 67% of children on the autism spectrum. Additionally, Green et al. (2009) assessed 101 autistic children using the Movement Assessment Battery for Children (Henderson, 1992; Henderson, Sugden, & Barnett, 2007) and found that 79% of children had movement impairment and another 10% were rated as "borderline impaired". In addition to motor difficulties, it is frequently observed that cognitive skills, such as executive function (EF), are altered in autistic individuals (Demetriou et al., 2018). It is believed that EF difficulties have an important role in ASD. Arising from reduced regional coordination and integration of prefrontal executive processes that combine emotion and social circuits, executive dysfunction may relate to some of the core autism-specific traits associated with the condition, such as social cognition and social challenges (Leung, Vogan, Powell, Anagnostou, & Taylor, 2016; Maximo, Cadena, & Kana, 2014).

Due to the complex symptomology, including social, cognitive, and motor differences and the vast heterogeneity of the disorder, there are no pharmacological or behavioral interventions that successfully target *all* functionally impairing features observed in ASD. For example, whilst Early Intensive Behavioral Intervention for young autistic children is a well-established intervention, research has indicated that it does not improve autism severity or support behavior that challenges; warranting caution as an effective behavioral intervention (Reichow, Hume, Barton, & Boyd, 2018). Additionally, some autistic individuals do not want to participate in interventions as they see their diagnosis as an inherent part of their being – autistic is *who* they are (Vivanti, 2020). However, some individuals on the autistic spectrum may need help and support for certain activities or therapeutic intervention to improve their quality of life. Therefore, current research suggests that interventions should aim to target and reduce specific and functionally impairing features associated with the condition in a person-centered manner (Galpin et al., 2018; Nicholas et al., 2020; Therrien Michelle & Light Janice, 2018).

1.2. *Physical activity and exergames*

Physical activity (PA) and exercise have been shown to have beneficial effects for young autistic individuals; alleviating some of the adverse autism-specific traits associated with the condition. Several reviews are available that highlight the potential of PA for improving or enhancing different facets of ASD including physical and mental health, self-regulation, cognitive development, and social-emotional functioning for children (Sam & Tong, 2015), adolescents (Sorensen & Zarrett, 2014), and adults (Colombo-Dougovito & Lee, 2020; Elliott, Dobbin, Rose, & Soper, 1994). Despite the somewhat promising relationship between ASD symptomology and PA, autistic individuals are less likely to engage in PA and exercise than their typically-developing peers (Bandini et al., 2013; Fitzgerald & Yip, 2017). Further, engagement in PA is likely to decrease as autistic children transition into adolescence.

Correspondingly, individuals on the autistic spectrum are more likely to engage with video or computer games than other

Table 1
Criteria for inclusion or exclusion of study in the review.

Inclusion criteria	Exclusion criteria
In English	Not in English
Included children or young autistic individuals	Included no individuals with a diagnosis of ASD
Published between 1990 and 2020	Published before 1990 or after 2020
Participants aged between 6 years old and 18 years old	Participants younger than 6 years old or older than 18 years old
Intervention must be an exergame or active video game	Intervention is not an exergame or active video game
Outcome measures focus on non-fitness specific measures; for example, cognitive measures, social measures or motor measures	Outcome measures only focus on fitness-specific outcomes; for example, heart rate or calories expended
Research articles	Conference abstracts, conference papers or reviews

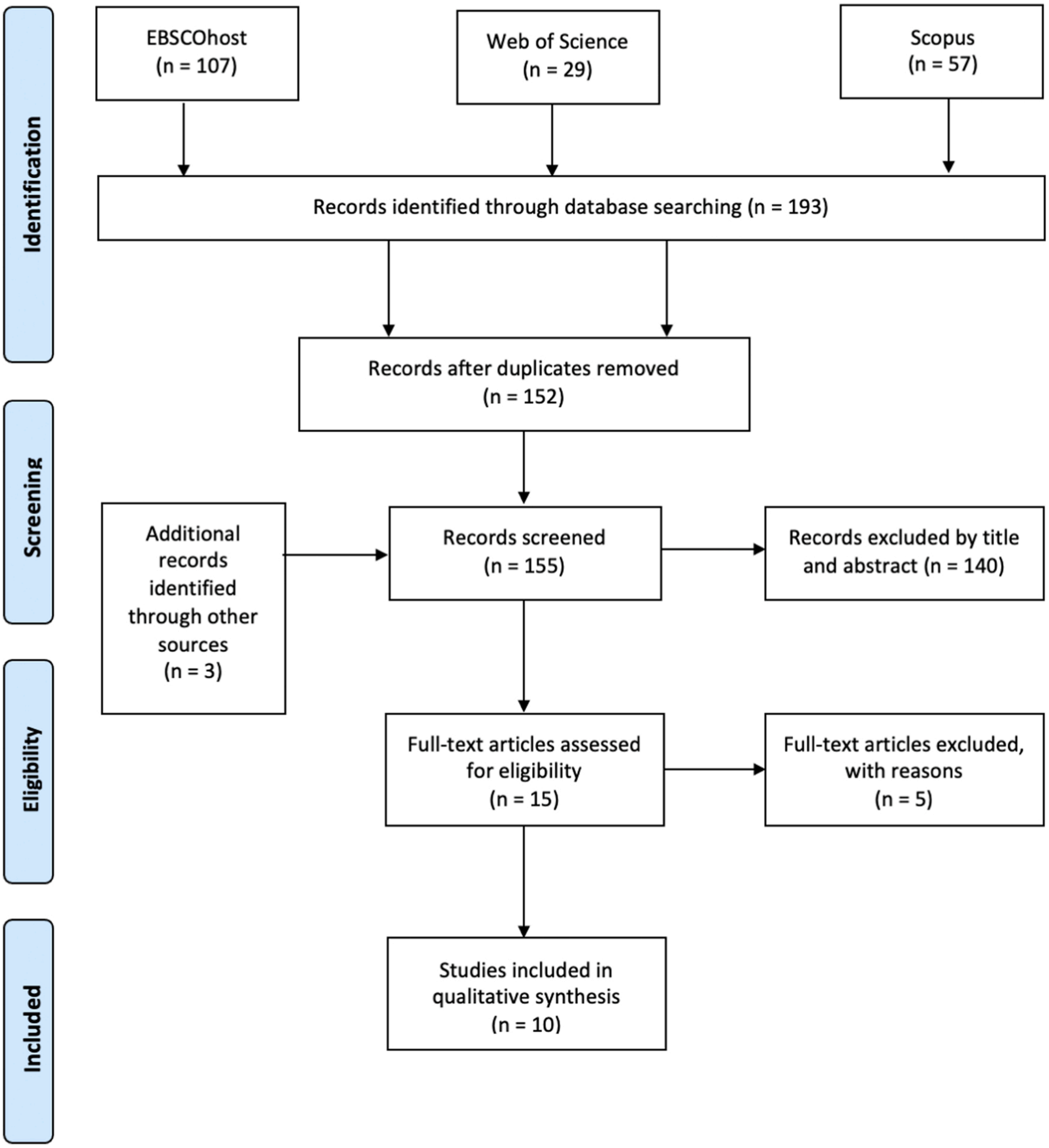

Fig. 1. PRISMA diagram for the flow of information through the different phases of the systematic review (Moher et al., 2009).

populations, with online gaming increasing from childhood to adolescence in autistic individuals (Engelhardt, Mazurek, & Hilgard, 2017; Mazurek & Wenstrup, 2013; Mazurek, Shattuck, Wagner, & Cooper, 2012). It is thought that videogames are particularly attractive to autistic individuals as they often offer low social demand, are consistent and predictable, and allow the user/player to determine the pace of the activity, taking active control (Durkin, 2010; Engelhardt et al., 2017). An innovative solution to increase PA in sedentary populations and draw up on the interests of videogaming platforms in many, can be found in the application of 'exergaming'. The term 'exergame' has many definitions associated with it. For example, Bogost (2007) defines exergames as "the combination of exercise and video games" (pg. 294), whereas as Oh and Yang (2010) redefined exergames as "an experiential activity in which playing exergames or any videogames requires physical exertion or movements that are more than sedentary activities and also include strength, balance, and flexibility activities". More recently, Kappen, Mirza-Babaei, and Nacke (2019) defined exergames as "the combination of gaming technologies and exercise routines to motivate physical activity among individuals or groups" (pg. 142). For the purpose of this review, we will be drawing upon Kappen et al.'s (2019) definition, where exergames are the combination of gaming technologies and exercise routines encouraging physical activity in autistic children. Exergames; combining videogaming technology with exercise, could offer the perfect platform to increase PA in young autistic individuals. Furthermore, the application of exergames may harness the potential therapeutic benefits of PA for reducing some of the features associated with ASD that impact

Table 2
Characteristics of studies that met all the inclusion criteria, including study design, sample size, exergame platform used for the intervention and duration of intervention, outcome measures and findings.

Authors	Title	Study Design		Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
Anderson-Hanley et al. (2011)	Autism and exergaming: effects on repetitive behaviors and cognition	A within-subject experimental design, with A-B exposure; 2 pilot studies (I & II)	***Pilot I***	$N = 12$; 8 males and 4 females; 10–18 years old (14.8 years old). All individuals had an ASD diagnosis	Kinect	Conducted across two weeks. Week one, participants completed the control condition, watching a 20-minute video of a school talent show. Week two, participants completed the exergaming session, engaging in Dance, Dance Revolution (DDR) for at least 20 min	Repetitive behaviors were measured by observations whilst playing for 5 minutes with Lego or Play-Doh, coded according to the repetitive scale of the Gilliam Autism Rating Scale-2. Cognitive functions were measured by the Digit Span Forwards and Backward Test, the Color Trails Test and the Stroop Task	Statistically significant condition × time interactions were found for repetitive behaviors ($P < .001$, Digits Backwards ($P < .05$) and Stroop Task ($P < .05$). Repetitive behaviors decreased after exergaming compared with the control condition ($P > .05$), whilst performance on the Digits Backwards improved ($P > .05$). Time to complete the Stroop Task and the Color Trials Test decreased for both the control and exergaming condition, with the control condition improving the most	The significant interactions suggest that the relative change from pre to post in the intervention condition was significantly different from the change in the control condition revealing improvements after exergaming (for both DDR and cyber-cycling) when compared with the control condition, for repetitive behaviors and at least one measure of executive function within subjects. However, given the short intervention session it is difficult to attribute these differences to participation in the exergame
			Pilot II	*$N = 10$; all male; 8–21 years old (13.2 years old). All individuals had an ASD diagnosis*	*Cyber-cycling*	*Same as above, however completed cyber-cycling instead of DDR*	*Same as above, however did not measure the Color Trails Test*	*Statistically significant condition × time interactions were found for repetitive behaviors ($P < .05$) and Digits Backwards ($P < .05$). Repetitive behaviors significantly decreased after cyber-cycling ($P < .05$), whilst performance on the Digits Backwards test improved ($P < .001$, compared with the control condition*	
Caro et al. (2017)	Using the FroggyBobby exergame to support eye-body coordination development of children with severe autism	Repeated measures deployment study		$N = 7$; 6 males, 1 female; 7–10 years old (8.62 years old). All individuals had an ASD diagnosis and were non-verbal	Kinect	Conducted within a school environment. Participants completed ~10-minute exergaming sessions, twice a week for 6 weeks. They played up to 6	Weekly interviews were conducted with the child's psychotherapists, acting as proxies to the children's potential answers. All exergame sessions were videoed to be observed and later coded based on a	Emotional expression: when expressing emotions (representing 30% of the total time of the game session), the majority of emotions were positive (99%). Attention: on average, children were focused in	The results indicate children with 'severe' autism maintained positive emotions and their attention throughout the total duration of the exergaming intervention.

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Authors	Title	Study Design	Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
					levels of FroggyBobby	framework quantifying children's behaviors and interactions with the game; such as, emotional expression, attention, motor performance and prompts	each session for 98% of the time, there was no significant change in attention from the first session to the last session. Motor: statistical significance was found in the percentage of time of aimed limb movements across the game sessions ($P < .05$) and aimless limb movements decreased significantly across the game sessions ($P < .05$). Prompts: results showed a significant decrease in the percentage time that children needed verbal prompts across the game sessions from 99% to 61% ($P < .0001$)	Furthermore, aimless limb movements were observed to decrease throughout the session, whereas successful aimed limb movements were observed to increase throughout the six weeks of the exergame within subjects
Chung et al. (2015)	Social Behaviors and Active Videogame Play in Children with Autism Spectrum Disorder	Single-case, within-subject experimental design, with an A-B-A exposure, observational study	$N = 6$; 4 males, 2 females; 6–12 years old (10.6 years old). 3 pairs of dyads, consisting of the 'target' child who had an ASD diagnosis and their sibling	Kinect	Conducted within the home environment. Each dyad (autistic child and their sibling) completed a maximum of 3, 30-minute gaming sessions per week for 12 weeks (12 sessions in total). The format was 4 control sessions based on sedentary videogames, 6 exergaming intervention sessions based on Kinect active videogames, and then 2 control sessions again	All sessions were videotaped. Primary measures were observed and evaluated using a coding manual with measures for joint positive effect, reciprocal conversation and aggression. Parental interviews were also conducted	Dyad A: the intervention condition resulted in a mild elevation of joint positive effect but a decrease in reciprocal communication. Aggression was unchanged. Dyad B: the intervention condition resulted in a decrease in reciprocal communication and no changes in aggression and joint positive affect. Dyad C: the intervention condition resulted in decreases in joint positive affect and reciprocal communication. Aggression was unchanged. All parents reported the active videogaming sessions	In ASD children who already played sedentary videogames, active video gaming (exergames) did not sustainably improve the quality of social engagements with their siblings over sedentary video gaming. A larger sample size and the use of standardized assessment are need to explore this further.

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Authors	Title	Study Design	Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
							were more positive social experiences than the sedentary gaming sessions	
Collins et al. (2015)	Exergaming to improve physical and mental fitness in children and adolescents with Autism Spectrum Disorders: Pilot Study	Repeated measures pre- and post-test experimental design	*N* = 17 (13 due to drop out); 12 males, 5 girls; 8–18 years old (11.76 years old). All individuals had an ASD diagnosis	Makoto Arena	Conducted at the Clayton Child Center or the Washington University School of Medicine for 8 weeks. Participants completed up to 3, 2-minute sessions of Makoto arena intervention in a row each day with a rest period between	Executive function was measured by the Behavior Rating Inventory of Executive Function (BRIEF) and motor skills were measured by the Bruininks-Oseretsky Test of Motor Proficiency-2 (BOT-2)	The BRIEF overall score, the global executive composite, showed a significant improvement ($P < .05$). The metacognition index change was also significant ($P < .01$). The behavioral regulation index showed a large effect size but was not significant. BOT-2 scores showed significant improvement only in the motor area of strength and agility ($P < .01$)	The use of exergaming, specifically the Makoto arena, may be useful for improving EF and motor skills in autistic children and adolescents. However, future work is needed to confirm this with control or comparison conditions
Edwards et al. (2017)	Does playing a sports active video game improve object control skills of children with ASD	Two-arm repeated measures pre- and post-test experimental design	*N* = 30;ASD group *N* = 11; 8 males, 3 females; 6 − 10 years old (7.64 years old);TD group *N* = 19; 10 males, 9 females 6–10 years old (7.89 years old)	Kinect	ASD participants; conducted within the home environment for 2 weeks. Each child engaged in Kinect Sports Season 1/2 or Sport Rivals for 45–60 min, 3 times a week (6 sessions in total). TD participants; delivered in their schools where each child completed 50-minute gaming sessions once a week during school lunchtimes for 6 weeks (6 sessions in total)	Control skills were measured by actual (Test of Gross Motor Development; TGMD-3) and perceived object skills (Pictorial Scale of Perceived Movement Skill Competence for Young Children). Parents also completed an interview post-intervention	There no were significant increases between the pre- and post-intervention mean scores on the TGMD-3 for the ASD group. Perception of skill in the ASD group significantly increased by 2 units ($P < .05$). Parents reported exergaming was a feasible intervention, though smaller, more frequent sessions would better fit into the daily routine and keep the children engaged	Exergaming was not observed to improve object control skills in this autistic sample. However perceived competence was reported to increase
Flynn and Colon (2016)	Solitary Active Videogame Play Improves Executive Functioning More Than Collaborative	Repeated measures pre- and post-test experimental design	*N* = 36 children; 25 males, 11 females; 7–18 years old; (12.31 years old) All children had	Wii	Participants were randomly assigned to playing alone or paired play conditions and then	Parents completed a demographic questionnaire, and both children and parents completed a short media	There were no differences in the frequency of overall videogame play or active video game by	Children enjoyed playing the exergame Just Dance 4 and, when they played alone, they improved their

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Table 2 (*continued*)

Authors	Title	Study Design	Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
	Play for Children with Special Needs		cognitive, social, and emotional disabilities, with 34% having an ASD diagnosis		participated in the exergame Just Dance 4, dependent on the condition for an average of 20 minutes	questionnaire to measure media exposure. Each participant's level of enjoyment during the activity was measured at the end of each activity session with the question, "How much did you like the activity you just did?''. The Stroop Task and Flanker Task were used to measure executive function	condition. On average, participants enjoyed their experience and there were no significant differences in enjoyment by condition. Participants in the playing-alone condition had a significantly larger change from pre- to post-test on the Stroop task when compared to the paired-play condition ($P < .05$). In addition, participants in the playing-alone condition had a significantly larger change from pre- to post-test on the flanker task when compared to the paired-play condition ($P < .05$)	executive function from pre- to post-intervention. The findings support previous studies that have shown that children with additional needs can improve Executive Function through active videogames play when they play alone
Hilton et al. (2014)	Effects of exergaming on executive function and motor skills in children with ASD: a pilot study	Repeated measures pre- and post-test experimental design	$N = 7$; 5 males, 2 girls; 6–13 years old (9.8 years old). All individuals had an ASD diagnosis	Makoto Arena	Conducted at the Clayton Child Center or the Washington University School of Medicine. Participants completed 2-minute sessions of Makoto arena intervention for a minimum of 3 times per week (30 sessions in total)	Executive function was measured by the BRIEF and motor skills were measured by the BOT-2	Significant improvements were observed in the BRIEF's Working Memory scale ($P < .05$) and the Metacognition Index ($P < .05$). Improvements were observed in all areas of the BRIEF except the Inhibit scale. Motor scores showed significant improvement only in the motor area of strength and agility ($P < .05$), with some improvement was also noted in manual coordination and total motor composite	This pilot study provides initial evidence that exergaming, specifically Makoto arena, may be useful for improving EF and motor skills in children on the autism spectrum. However, future work is needed to confirm this with control or comparison conditions
Lau et al. (2020)	Effectiveness of active video game usage on body	Two-arm parallel, single-blinded trial	$N = 203$; Intervention $N = 125$; 92 male,	Kinect	Conducted with a school setting for 12 weeks. Participants	Body composition and PA level measured by ACTi Graph GT3X	Body composition increased for both groups. Children's BOT-	Exergames showed positive results, however were unable to

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Authors	Title	Study Design	Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
	composition, PA level and motor proficiency in children with intellectual disability		33 female, 8–18 years old (mean unknown); Control *N* = 78; 54 males, 24 females, 8–18 years old (mean unknown). All had an intellectual disability; 51.2% had comorbid autism		completed two 30-minute intervention sessions per week, playing Kinect Sport Season Series 1 and 2. Control group received no intervention and continued with PA as usual	+ activity monitor. Motor proficiency was measured by the BOT-2	2 scores increased from 53.85 at baseline to 57.36 at post-test in the intervention group (P < .001), while it increased from 57.86 at baseline to 59.20 at post-test in the control group (P < .01). However, this was not statistically significant between groups	improve motor proficiencies, body composition or PA levels over and above that of the control group who completed physical activity as usual
Rafiei Milajerdi et al., 2020	The effects of PA and Exergaming on Motor Skills and Executive Functions in Children with ASD	Randomized controlled trial	*N* = 60; SPARK *N* = 20; 19 males, 1 female; 6–10 years old (8.45 years old); Kinect *N* = 20; 19 males, 1 female; 6–10 years old (7.95 years old); Control *N* = 20; 19 males, 1 female; 6–10 years old (8.15 years old). All individuals had an ASD diagnosis	Kinect	Conducted within the Iran Autism center. Children were randomly assigned to either the SPARK (Sports, Play and Active Recreation for Kids) group, Kinect Tennis group, or Control group. Children assigned to the SPARK and Kinect groups completed 35-minute sessions, three times a week, over 8 consecutive weeks (24 sessions in total). Children in the control group did not participate in any structured PA program and continued with treatment as usual during the study period	The Movement Assessment Battery for Children-Second Edition (MABC-2) was used to measure motor skills and the Wisconsin Card Sorting Test (WCST) was used to measure executive function both pre- and post-test	Motor: There was a significant group x time interaction for aiming and catching (P < .05), where an improvement in aiming and catching on the MABC-2 from pre-test to post- test was observed in the SPARK group, whereas the Kinect group showed a decrease in these skills. The control group displayed a limited change in aiming and catching from pre- test to post-test. Executive function: there was a significant main effect of group for the number of correct responses during the WCST (P < .01). Post hoc comparisons revealed statistically significant differences between the Kinect and control group, and between the Kinect and SPARK group, where the Kinect group performed better	This study showed that a structured traditional PA intervention that targets specific motor skills resulted in motor function improvement in children with ASD. The findings also suggest that exergaming may improve EF in children with ASD; however, future research is warranted
Pope et al. (2019)	Comparison of exergaming and adaptive physical education on PA, on-task behavior	Mixed methods observational study	*N* = 5; all males; 5.5–10.5 years old (6.8 years old). All individuals had an ASD diagnosis	Wii	Conducted within a school environment for 3 weeks. Each child completed three sessions of	Sedentary behavior, light PA and moderate-to-vigorous PA measured via an accelerometer during each condition.	Children had a high affinity for Just Dance 4. Exergaming condition had higher average minutes of MVPA and	Exergames can increase levels of PA and promote on-task behavior and communication.

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Table 2 (*continued*)

Authors	Title	Study Design	Sample size; gender; age (mean age)	Platform	Intervention; delivery and occurrence	Outcome measures	Findings	Authors Conclusions
	and communication in children with ASD				exergaming, specifically Just Dance 4 or Wii Sports, and Adaptive Physical Education (6 sessions in total)	Direct observations during each condition including coded on task and attentive behaviors and communication	lower average of LPA. Direct observation revealed greater percentage of on-task behavior during AdPE than exergaming and a high percentage of communication also seen in AdPE	However, in this study, AdPE was observed to be better at promoting on-task behavior and communication than exergames

(DDR; Dance Dance Revolution, ASD; Autism Spectrum Disorder, PA; Physical Activity, BRIEF; Behavior Rating Inventory of Executive Function, SPARK; Sports, Play and Active Recreation for Kids, TGMD-3; Test of Gross Motor Development-3, BOT-2; Bruininks-Oseretsky Test of Motor Proficiency-2, LPA; light physical activity, MVPA; moderate-to-vigorous physical activity, MABC-2; The Movement Assessment Battery for Children-Second Edition, WCST; Wisconsin Card Sorting Test.Figures and Legends.

quality of life, whilst also being engaging and enjoyable for many autistic individuals.

Due to the vast array of available exergames previous research has indicated that exergames can be effective interventions for supporting an array of developmental skills, including social, cognitive, and motor development, and also rehabilitation in many different populations and clinical samples. For example, exergames have been observed to have some positive effects for self-concept, situational interest and motivation, enjoyment, psychological and social well-being, symptomatology and different learning experiences for TD children and adolescents (see Joronen, Aikasalo, & Suvitie, 2017 for review). In addition, children and adults with cerebral palsy have shown positive responses to participating in Wii Sports, which involves performing the actions associated with tennis, baseball, bowling, golf and boxing, and Wii Fitness (Deutsch, Borbely, Filler, Huhn, & Guarrera-Bowlby, 2008; Jelsma, Pronk, Ferguson, & Jelsma-Smit, 2013). Similarly, individuals with down syndrome have also shown significant improvements in physical fitness and functional outcomes (Perrot, Maillot, Le Foulon, & Rebillat, 2020) and motor proficiencies after participating in Wii-based exergames (Silva et al., 2017). Furthermore, exergaming was an effective intervention for temporarily enhancing balance and reducing fatigue in individuals diagnosed with Parkinson's disease after 12 weeks of Wii Fit games (Ribas, Alves da Silva, Corrêa, Teive, & Valderramas, 2017). Kappen et al. (2019) provides a good overview of the diversity and use of exergames for older adults. Therefore, due to the rapid development of computer technology, promising results in various clinical populations, and young autistic individual's interest in electronic media (i.e., videogames), more research is needed to better understand and establish the benefits of exergames for ASD.

Many studies have focused on the impact of exergames for increasing PA levels in autistic individuals, in an attempt to decrease sedentary behaviors and improve fitness-related outcomes such as heart rate and calories burned (Fang, Aiken, Fang, & Pan, 2018; Finkelstein, Barnes, Wartell, & Suma, 2013; Finkelstein, Nickel, Barnes, & Suma, 2010; Hilton et al., 2015; Jozkowski, Lichtenwalner, & Cermak, 2016). Whilst these studies have shown promising results for fitness-related outcomes, they do not account for how exergames could influence any of the well-recognized facets associated with ASD. Therefore, some studies have since focused their efforts on examining the effect of exergames for some of the specific domains that are commonly affected in ASD, such as motor skills, cognitive function or social capabilities. However, no review to date has acknowledged and highlighted the potential beneficial effects of exergames for alleviating the impairing symptomology associated with the ASD, exclusive of PA levels/fitness-related outcomes.

Therefore, the purpose of this systematic review is two-fold. First, we aim to pool all the existing research relating to the non-fitness/non-physical-health-related effects of exergames; such as cognitive, social, or motor functions, for young individuals diagnosed with autism. Secondly, we aim to collate the available evidence that suggests exergames are a viable vehicle for therapeutic intervention targeting some of the limiting differences observed in ASD. In addition, we hope to provide a direction for future research to develop tailored exergame-based interventions for young autistic individuals that will support the development of communication skills, a core facet of ASD, in a person-centered manner; promoting quality of life and well-being.

2. Methods

2.1. Research question

To provide a summary of the current evidence relevant to the non-fitness-related impacts of exergames for young autistic individuals and to investigate whether exergames can elicit positive effects for autistic individuals, we utilized the PICO strategy to devise a central research question. PICO is a widely recognized model often used for structuring research questions in connection with evidence syntheses, where: P: population, patient or problem; I: intervention, C: control or comparative intervention, and O: outcome (Eriksen & Frandsen, 2018). Using the PICO framework, the following research question was generated; *"To what extent can exergames have non-fitness-specific beneficial effects for young individuals diagnosed with Autism Spectrum Disorder?"*. We appreciate that some studies may use varying study designs; including, within-subject study designs, comparing the effects of an exergame by pre- and post-intervention tests and an initial review of the literature suggested that there were limited studies available for review that included a comparison group. Therefore, we elected to not specify the inclusion of a control group or comparative intervention in our research question; considering the limitations this begets in the discussion.

2.2. Literature search

We searched a total of six databases for the most appropriate and relevant studies that corresponded to the specific objectives of this review. Databases included Scopus, Web of Science, and EBSCOhost; together with PsycArticles (American Psychological Association – APA), PsycINFO (APA), SPORTDiscus and MEDLINE. The key search terms consisted of the descriptives; "autism", "ASD", "autism spectrum disorders" "child*" "young", "exergames", "virtual physical activity*", "exercise games", "exergaming", "positive", "benefi*", "social", "communi*", "impact", "behavior", "effect*", alongside the Boolean operators; "and" and "or".

2.3. Inclusion and exclusion criteria

Studies were included in the review if they met the inclusion criteria. For example, studies were included if they were in English, published between 1990 and 2020, included participants aged between 5 and 18 years old, where most participants had a diagnosis of ASD, used an exergame as an intervention, and measured the effect of the intervention with reported outcome measures that focused on skills such as social, cognitive or motor proficiencies. Studies were excluded if the papers were not in English, participants were older than 18 years old, and/or if the outcome measures focused only on PA levels or fitness-related outcomes; for example, heart rate, calories burned or moderate-to-vigorous PA levels, as this was not the main focus of the systematic review. Additionally, conference papers and review articles were excluded (Table 1).

2.4. Selection of studies and extraction of data

Following the PRISMA guidelines for systematic reviews, an orderly procedure was carried out to select the most relevant articles to include in the review from the literature search (Moher, Liberati, Tetzlaff, Altman, & Group, 2009). During the first phase of the procedure, we combined all extracted articles from the literature search into a single folder, removing any duplicates. Adhering to the inclusion and exclusion criteria, we selected articles to exclude based on their titles and then articles to exclude based on their abstracts. Using the 'Dual Independent Review Approach' of the search results, the first author and an independent reviewer (TM) both screened the titles and abstracts to ensure reproducibility in the inclusion and exclusion criteria (Stoll et al., 2019). The remaining articles were all read fully and brief notes were made on each of the study's characteristics, including title and author, study design, participants used, intervention utilized, and outcome measures, whilst still assessing them against the inclusion and exclusion checklists (Table 1). Additionally, the reference lists of relevant articles were read, seeking studies that were appropriate for inclusion but had been missed by the search parameters (n = 3). Papers that met all the inclusion criteria and were relevant to the central research question were all read fully again in order to finalize articles to include for evidence synthesis (Fig. 1).

Once the final studies to include in the review had been selected, data was extracted to retrieve particular information regarding each study, including; title, authors and date, study sample and size, exergame platform used, outcome measures utilized, findings, and conclusions.

2.5. Assessment of risk of bias for included studies

As reported in the Cochrane handbook, bias "is a systematic error, or deviation from the truth, in results or inferences" (Boutron et al., 2019), where different biases can lead to an over or underestimation of the true effect of an intervention. It is important to assess bias in all studies included in the review to ensure accurate conclusions can confidently be made from the synthesis of the available literature. However, it is often impossible to know the extent that biases have affected the results of a particular study. Therefore, it is more appropriate to reflect on the 'risk' of bias of a particular study. We employed the Cochrane risk assessment guidelines to determine whether the risk of bias was low, high, unclear or not applicable (if non-randomized study) for selection bias (random sequence generation and allocation concealment), performance bias (blinding of participants and personnel), detection bias (blinding of outcome assessment), attrition bias (incomplete outcome data), reporting bias (selective reporting), and any other potential bias.

3. Results

3.1. Study selection

The initial literature search identified 193 studies that met some of the key terms relating to the research question (Scopus, n = 57; Web of Science, n = 29; and EBSCOhost, n = 107). An additional three studies were identified by examining the reference list of relevant papers. After removing duplicates, screening papers based on titles, and then screening based on abstracts, 15 potential papers remained. To this end, the level of agreement between the two reviewers, who both screened the articles by titles and abstracts, was calculated using Cohen's Kappa (McHugh, 2012). The weighted kappa score for agreement between the reviewers was 0.797, 95% Cl: 0.626–0.969, indicating substantial agreement (Landis & Koch, 1977).

The 15 papers were fully read and assessed against the inclusion and exclusion criteria. A total of 10 papers met the inclusion criteria and, therefore, were included in the review. These can be seen in Table 2. Most of the included papers were repeated measures, pre- and post-test study designs (Caro, Tentori, Martinez-Garcia, & Zavala-Ibarra, 2017; Collins, Attal, & Hilton, 2015; Edwards, Jeffrey, May, Rinehart, & Barnett, 2017; Flynn & Colon, 2016; Hilton et al., 2014). However, two were within-subject experimental designs with an A-B and A-B-A exposure (Anderson-Hanley, Tureck, & Schneiderman, 2011; Chung, Vanderbilt, & Soares, 2015, respectively), one was a two-arm parallel single-blinded trial (Lau, Wang, & Wang, 2020), and another was a mixed-methods observational study (Pope, Fautsch, Zeng, & Gao, 2019). Only one study included in this review was a randomized controlled trial (Rafiei Milajerdi et al., 2020).

3.2. Study characteristics

3.2.1. Characteristics of participants

As this review focuses on the effects of exergaming for young autistic individuals, we chose not to include studies that had participants over the age of 18 years old. All participants were aged between 5 and 18 years old, with one exception. Anderson-Hanley et al.'s (2011) pilot study II included individuals aged between 8 and 21 years old. We have included this pilot study in the table of characteristics, however will not be drawing conclusions from this part of their study due to the participant's ages. The average age of participants included in the review, excluding Lau et al.'s (2020) study as they did not report mean age, was 9.56 years old.

Most participants had a diagnosis of ASD, according to the Diagnostic and Statistical Manual of Mental Disorders IV or V (DSM-IV; DSM-V; American Psychiatric Association, 2013). The Autism Diagnostic Observation Schedule-Second Edition (ADOS-2; Lord et al., 2012) and the Gilliam Autism Rating Scale-Second Edition (GARS-2; Gilliam, 2005) were also used to assess autism severity and confirm a diagnosis. Some studies, such as Lau et al. (2020) and Flynn and Colon (2016) included participants that had various difficulties or intellectual disabilities, but where the majority of participants had an autism diagnosis. Additionally, typically developing (TD) participants were also included in Edwards et al. (2017) for between-group comparisons.

3.2.2. Characteristics of interventions

Interventions varied in duration. Some studies concluded within a day, whilst others lasted 12 weeks. Flynn and Colon (2016) and Anderson-Hanley et al. (2011) both used a single, 20-minute intervention session to assess the effect of their chosen dance-based exergame on participant's EF, repetitive behaviors, and cognition. In comparison, Hilton et al. (2014) and Rafiei Milajerdi et al. (2020) conducted their interventions across 8 weeks, in which participants were required to complete several sessions of their chosen exergame; Makoto Arena and Kinect, respectively, each week. Chung et al. (2015) and Lau et al. (2020) both utilized the Kinect platform, requiring participants to complete up to 3 exergame sessions a week, for 12 weeks. However, Chung et al. (2015) directed autistic children to play the Kinect-based exergame with their TD sibling in the home environment, whilst Lau et al. (2020) asked autistic children to be 'paired-up' by their teachers and complete the intervention in a school environment. Across all studies, the average intervention duration was 6 weeks and the most popular platform utilized was Kinect, followed equally by Makoto Arena and Wii. The most popular type of active video games played were dance-based games, such as Wii's *Just Dance* or Kinect's *Dance Dance Revolution*. However, sports-based games such as Sports Season 1 and 2 or Kinect Tennis were also played frequently.

3.2.3. Characteristics of outcome measures used

The studies included in this review examined a variety of potentially beneficial outcomes of exergames for young autistic individuals including social, cognitive, and motor benefits. They did not, however, focus on or investigate the fitness-related benefits of exergames, as this was not the main aim of the review. Overall, 7 of the studies investigated the effect of exergames on cognition, most frequently EF, 7 of the studies examined motor function, and only 2 of the studies explored social behaviors. It is therefore apparent that some studies investigated the effects of exergames on both cognition and motor skills (Anderson-Hanley et al., 2011; Caro et al., 2017; Collins et al., 2015; Hilton et al., 2014).

To assess EF, tasks such as the Stroop Task (Stroop, 1935), Wisconsin Card Sorting Task (WCST; Grant & Berg, 1948), and the Digit Span Backwards Task were used (see Ramsay & Reynolds, 1995 for an overview). They were often administered pre- and post-intervention. To examine the effect of exergames on motor skills and motor proficiencies most studies enlisted the Bruininks-Oseretsky Test of Motor Proficiency-Second Edition (BOT-2; Bruininks & Bruininks, 2005), however one study used the Movement Assessment Battery for Children-Second Edition (MABC-2; Henderson et al., 2007) and another used the Test of Gross Motor Development-Third Edition (TGMD-3; Ulrich, 2016). When exploring the effect of exergames on social behaviors, Pope et al. (2019) and Chung et al. (2015) both videotaped their participants during intervention sessions, subsequently observing the tapes to score behaviors according to a coding manual and to assess changes in social behaviors.

3.3. Study findings

3.3.1. Executive function

Overall, some studies found within this review reported that exergaming produced certain benefits for young autistic individuals. Collins et al. (2015), Flynn and Colon (2016), Hilton et al. (2014), and Rafiei Milajerdi et al. (2020) all noted improvements in EF following their exergame-based interventions. Both Collins et al. (2015) and Hilton et al. (2014) utilized the Behavior Rating Inventory of Executive Function (BRIEF) to measure changes in EF and both observed improvements in all areas of the inventory. Collins et al. (2015) reported a significant improvement in global executive composite ($P < .05$) and metacognition index ($P < .01$) and Hilton et al. (2014), reported a significant improvement in the specific areas of working memory ($P < .05$) and global executive composite ($P < .05$). Rafiei Milajerdi et al. (2020) used the WCST as a measure of EF. They showed that on average the exergaming group were able to significantly improve their correct responses on the WCST, between pre- and post-test from 0.50 ± 0.71–1.52 ± 2.00, which was greater than both the control and SPARK (Sports, Play and Active Recreation for Kids) groups included within the study ($P < .05$); thus, suggesting an improvement in set-shifting and mental flexibility due to exergaming.

3.3.2. Motor Skills

Caro et al. (2017), Collins et al. (2015), and Hilton et al. (2014) all reported an improvement in motor skills. Caro et al. (2017) demonstrated that '*FroggyBobby*' was able to increase the percentage of time participants spent performing aimed limb movements from 56% in the second session to over 96% in the twelfth session, suggesting a significant improvement in motor coordination ($P < .05$). Collins et al. (2015) compared the means of pre- and post-test scores for the BOT–2 during their study, with results suggesting an improvement in all areas of the BOT-2 and a significant improvement in the motor area of strength and agility ($p < .01$) with a large effect size ($r = .54$). Similarly, Hilton et al. (2014) also noted a significant improvement in the motor area of strength and agility in the BOT-2 scores following their '*Makoto Arena*' intervention ($P < .05$), with a small to medium effect size ($d = .46$). Edwards et al. (2017) suggested that during their study exergames were unable to produce an improvement in actual motor skills but instead were able to increase the participant's perceived object-motor skills by approximately 2 units, from an average score of 27.36 ± 3.85–29.45 ± 3.91, on the Pictorial Scale of Perceived Movement Skill Competence ($P < .05$), which in future may have led to an improvement in actual motor skills.

In comparison, Lau et al. (2020) reported that exergames were unable to improve motor proficiencies, body composition or PA levels over and above that of their control group during their study, as no significant improvements were observed between the intervention and control group. Despite children's BOT-2 scores increasing from 53.85 ± 15.25 at pre-test to 57.36 ± 15.00 at post-test in the intervention group and only increasing by two units from pre-test to post-test for the control group, after adjustment for the intervention group relative to the control group, differences for motor proficiency were found to be non-significant between groups.

3.3.3. Social skills

Chung et al. (2015) noted no substantial improvement in social behaviors, including positive joint affect, reciprocal communication, or aggression within their participants, following their active videogame intervention in comparison to the sedentary videogame condition. Pope et al. (2019) reported that exergames, mostly '*Just Dance 4*', were able to promote an increase in PA levels, on-task behaviors, and communication. However, their comparison condition, Adaptive Physical Education (AdPE), was able to achieve this on a greater scale. For example, percentage of time spent communicating during the AdPE condition was 34.0% ± 11.8 compared to 16.1% ± 10.1 in the exergaming condition.

3.3.4. Enjoyment

In addition to positive outcomes for the development of specific skills, many of the studies included in this review reported that children enjoyed participating in their exergaming interventions. Both Flynn and Colon (2016) and Collins et al. (2015) measured participant's responses to participating in their exergaming interventions via questionnaires. Collins et al. reported that 88% of their participants experienced some degree of enjoyment from playing the '*Makoto Arena*' exergame and Flynn and Colon (2016) reported that on average all participants enjoyed their exergaming experience. Similarly, Chung et al. (2015) received parent feedback

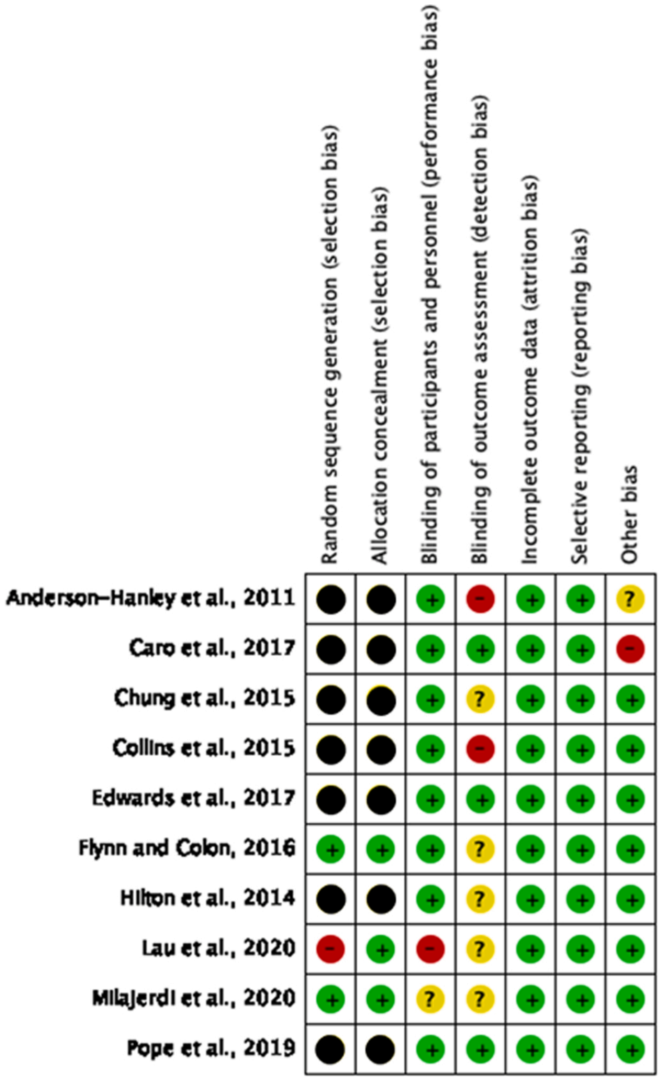

Fig. 2. Risk of bias summary for each study that met all the inclusion criteria, including high (red), low (green), unclear risk (yellow) of bias and not applicable (black).

following their exergaming intervention inferring that the '*Kinect*' games were a positive and enjoyable experience, which was engaging and social for their children. Likewise, Caro et al. (2017) suggested that 99% of the emotions displayed by participants, whilst playing the exergame, were positive emotions.

3.4. *Risk of bias*

Risk of bias, including low, high, and unclear risk, were reported for all studies according to selection, performance, detection, attrition and reporting bias (Fig. 2). However, the risk level was not applicable for all categories in each study. For example, studies that did not include two different groups (i.e intervention vs. control), did not need to randomly assign participants to different groups. Therefore, selection bias, with regards to random sequence generation, was not applicable for these studies.

Most studies were unable to blind participants due to the nature of the interventions; however, it was believed this would not affect the outcomes of the studies. Additionally, most studies did not blind personnel during the outcome assessments, which may have led to detection bias. Authors that accounted for this either by having multiple coders and assessors and reporting interrater reliability for their outcome measures were regarded as having low detection bias. However, studies that did not reference how they attempted to limit detection bias or failed to note how detection bias may have impacted their results were regarded as having an unclear or high risk of bias. In addition, the authors of the Caro et al. (2017) study were involved in the development of the exergame used in their deployment study and therefore were noted as potentially having a high risk of bias for 'other biases'.

4. Discussion

In answer to the research question "*To what extent can exergames have non-fitness-specific beneficial effects for young individuals diagnosed with Autism Spectrum Disorder?*" the results suggest that interventions based on exergames can produce some beneficial effects for young autistic individuals. These included improving EF, increasing motor proficiencies and, to some extent, promoting communication owing to the diversity of exergames and skills needed to play various exergames. Additionally, results from the studies included within this review suggest that participants enjoyed the exergames, which is a key component to helping autistic individuals engage with interventions (Finke Erinn et al., 2018). Flynn and Colon (2016), Collins et al. (2015), and Chung et al. (2015) reported that children enjoyed participating in their exergaming interventions, either via self-reported questionnaires or feedback from parents. Importantly, no study reported any adverse consequences for children participating in their exergaming-based intervention.

4.1. *Implications for practice and future work*

Online media such as videogames and exergames are believed to be intrinsically motivating for many autistic individuals and, falling in line with the available literature, the results from this review suggest that exergames are engaging, motivating, and enjoyable for young autistic individuals (Caro, Martínez-García, & Kurniawan, 2020; Finkelstein et al., 2010; Lyons, 2015). Furthermore, the availability of many different exergames that promote varying beneficial effects and involve different skills allow children to choose what games they want to play and have autonomy over their choices. It is thought motivation is essential for learning and is a key component in engaging with and committing to learn a new activity. Further, it is argued that the most optimal context for development is one that is selected based on the motivation and interests of the individual (Deci & Ryan, 2000; Koegel, 2000; Gee, 2009). Thus, illuminating why exergames may elicit positive changes in executive function and motor skills, and highlighting the strong potential exergames have for developing further skills, such as self-regulation, cooperative play, or communication skills, in young autistic individuals.

Recognizing that autistic individuals contend with various barriers throughout their day-to-day lives, challenges presented within videogames may be more manageable, enjoyable, and rewarding than the tasks presented in their everyday lives (Durkin, Boyle, Hunter, & Conti-Ramsden, 2013). Previous studies have indicated that individuals on the autistic spectrum play videogames for a variety of reasons, including emotional regulation, immersion, social interaction, achievement, creativity, and mental stimulation (Finke Erinn, Hickerson Benjamin, & Kremkow Jennifer, 2018; Mazurek, Engelhardt, & Clark, 2015). Given that exergames are observed to elicit some beneficial effects, are intrinsically motivating, and enjoyable for autistic individuals, it seems plausible that exergames can offer a viable platform for developing an array of skills in ASD in a therapeutic capacity, which is well-suited to the individual's interests. Exergames could be implemented into practice, with future work confirming the optimal duration and frequency of exergaming interventions and the ideal games to play for targeting specific domains of ASD. Further, exergames could readily and regularly be integrated into or in addition to schools' physical education programs to improve EF and motor skills in autistic children, following more rigorous studies confirming their benefits.

Despite poor social and communication skills being a core diagnostic trait of ASD and having a great impact on quality of life (QoL; Chiang & Wineman, 2014; Kuhlthau et al., 2010), only two studies were found by the systematic search to investigate the effect of exergaming on social behaviors in young autistic individuals. Both Chung et al. (2015) and Pope et al. (2019) observed communication and social behaviors during their exergaming conditions. Chung et al. (2015) reported no significant changes to positive joint affect, reciprocal communication, or aggression during their intervention condition; however, this study only included 3 participants who had an autism diagnosis in dyads with their TD siblings. Pope et al. (2019) noted an improvement in on-task behavior and communication in autistic participants ($n = 5$), however their AdPE condition produced a greater improvement in both outcome measures. As these were both observational studies with limited sample sizes, it may be beneficial to complete a pre- and post-intervention study design with a larger sample of autistic individuals; testing social skills using standardized measures before and after the intervention in order for stronger conclusions to be drawn from the findings.

It is noted that many autistic participants had a high affinity for dance-based exergames. Dance is a type of PA that emphasizes the importance of movement and fitness in a variety of ways but also allows one to express their feelings and emotion, communicating through the use of rhythm and body positions (Calvo, D'Mello, Gratch, & Kappas, 2015; Camurri, Lagerlöf, & Volpe, 2003). The use of dance has been extended to therapeutic practices, where dance movement therapy (DMT) is employed for a variety of clinical populations, including those with depression and anxiety (Adam, Ramli, & Shahar, 2016; Karkou, Aithal, Zubala, & Meekums, 2019), Parkinson's disease (de Natale et al., 2017; dos Santos Delabary, Komeroski, Monteiro, Costa, & Haas, 2018), and autism (Scharoun, Reinders, Bryden, & Fletcher, 2014; Takahashi, Matsushima, & Kato, 2019). Importantly DMT has been observed to improve communication skills in young autistic individuals, with dance and movement therapists reporting promising results through the successful use of mirroring, synchronous movement interaction, and rhythm (Cozolino, 2014; Devereaux, 2012; Martin, 2014; Tortora, 2005; Field et al., 2001; Koch et al., 2015). The techniques of mirroring and rhythm have consistently been observed to improve communication skills and social development in autistic children (Morris, Hope, Foulsham, & Mills, 2021). Both of these elements are found within dance-based exergames such as '*Just Dance*' (Wii), which requires the player(s) to rhythmically mirror/copy the avatar on screen. Due to this cross over between exergames and successful elements of DMT, it seems plausible that dance-based exergames may still be able to improve social skills, despite the previous findings from Pope et al. (2019) and Chung et al. (2015). More recently, '*Just Dance*' as compared to another almost identical movement-based intervention has been observed to produce significant positive psychological and psychosocial effects in a large sample of TD primary school children ($n = 417$; Quintas, Bustamante, Pradas, & Castellar, 2020). Therefore, future work should attempt to evaluate the beneficial effects of dance-based exergames on the social skills of young autistic individuals utilizing randomized controlled trials. Researchers could recruit an appropriate number of participants to allow for pre- and post-test comparisons of outcome measures between an intervention group (dance-based exergame) and a control group, where validated outcome measures relate to social skills; such as the Social Responsiveness Scale (Constantino, 2013), Social Skills Improvement Scale (Gresham & Stephen, 2007), the Emotion Regulation and Social Skills Questionnaire (ERSSQ; Beaumont & Sofronoff, 2008) and/or coded observations in a given context (Heimann, Laberg, & Nordoen, 2006; Nadel et al., 2000; White, Keonig, & Scahill, 2007).

The findings from this review suggest an exergame intervention based on a timeframe of 6-weeks or greater, with participants completing the exergame for 2-to-3 times per week may be an optimal starting point for future studies. If the results from such a study demonstrated beneficial effects, for example an improvement in the ERSSQ, which was specifically designed for use in the autistic population, exergames could be more confidently integrated into practice for the development of social skills in the autistic population.

4.2. Limitations

Some of the studies included in this review presented encouraging results for improving or maintaining specific domains affected within ASD. However, they are not without their limitations; restricting the conclusions drawn regarding the effectiveness of exergames for autistic individuals. Out of ten studies, only two included a control group; the first was a randomized controlled trial (Rafiei Milajerdi et al., 2020) and the second was a two-arm, single-blinded trial (Lau et al., 2020). One other study included an active comparison task for children to also complete (Pope et al., 2019). Although non-randomized controlled trials are useful for feasibility studies and still allow for the critical examination and analysis of the available evidence, it is somewhat difficult to draw conclusions that the intervention generates the observed outcome in studies that do not include control or comparison groups (Gerstein, McMurray, & Holman, 2019). Additionally, the absence of a control group prevents comparison of the experimental group to the changes that might be seen due to normal development, on-going therapies, or familiarity with the assessments (Collins et al., 2015). For example, whilst Caro et al. (2017) suggested that attention and enjoyability was maintained throughout their exergaming intervention, there is no indication or comparison available of what attention and enjoyability levels were prior to participating in the game or during a different intervention. To overcome this limitation and to confidently state exergames can elicit positive effects in young autistic individuals for a variety of traits, future studies need to include a control or active comparison group.

Small sample sizes were another reoccurring limitation across the studies reviewed. Recruiting participants with ASD can present potential barriers. For example, when data is collected in schools there often needs to be specific student-to-teacher ratios, and so, if limited teachers are available this can also limit the number of children available to participate in the study. Additionally, families with autistic children already face an array of challenges and require additional support, therefore participating in scientific research on top of educational, social, and therapy-based commitments may prove too much, and again limit the number of young autistic individuals available to participate. The overall sample size of autistic participants ranged from $n = 3$ to $n = 125$. Over half the studies included in this review had less than 17 participants overall (Anderson-Hanley et al., 2011; Caro et al., 2017; Chung et al., 2015; Collins et al., 2015; Hilton et al., 2014; Pope et al., 2019). However, most of these studies utilized a within-subject design, which is more practical than randomly assigning participants to an intervention type. This study design also has greater statistical power than a between-subject design when working with a small sample size (Bellemare, Bissonnette, & Kröger, 2014; Hilton et al., 2014; Thompson & Campbell, 2004). Only one study reportedly carried out a power analysis to determine the sample size needed for their analyses. Rafiei Milajerdi et al. (2020) concluded that with three groups at an 80% power with an $\alpha = 0.05$, 60 participants would be sufficient to detect medium group, time, and group x time effects. To more robustly assess the effectiveness of exergames as a therapeutic intervention for individuals who have a diagnosis of ASD, it would be beneficial for future studies to conduct experiments with larger sample sizes, using power analyses to determine sufficient sample sizes, which will allow for the inclusion of control groups and between-group comparisons.

No study included in this review chose to conduct a follow-up study. Despite some interventions lasting up to 12-weeks and producing beneficial effects, it was not clear whether these beneficial effects continued after the intervention ceased. Therefore, it is somewhat difficult to suggest long-term and applied utility of exergaming for ASD. Previous research has indicated that participation in PA interventions is able to produce long-lasting beneficial effects for autistic individuals (Gabriels, Pan, Guérin, Dechant, & Mesibov, 2018; Movahedi, Bahrami, Marandi, & Abedi, 2013). For example, Nicholson, Kehle, Bray, and Heest (2011) demonstrated that antecedent PA was able to improve academic engagement four weeks post-intervention and Bahrami, Movahedi, Marandi, and Abedi (2012) described behavioral gains that were maintained long-term (1 month), following a 14-week martial arts-based training program in autistic children. As a result, future work may wish to explore the maintenance of improvements following exergaming by performing a follow-up assessment.

5. Conclusion

This systematic review collates the available evidence that suggests exergames may be a viable vehicle to elicit some beneficial effects in young autistic individuals, exclusive of PA levels/fitness-related outcomes. Research suggests that exergames may reduce repetitive behaviors, improve EF, and increase motor skills to some extent. Future work should strive to determine the effects of exergames on social skills in young autistic individuals. Furthermore, prospective work is needed to overcome many of the limitations highlighted by this review; for example, establishing the optimal duration and frequency of exergames or whether positive results are maintained post-intervention. Caution is warranted to not overstate the benefits of exergames for the autistic population without the addition of robust studies to the literature, such as adequately powered randomized control trials to confirm the potential benefits of exergame that have been highlighted in this review. Such work may allow for exergames to be integrated into clinical practice or school routines, where exergames are utilized to support specific domains of ASD that negatively impact an individual's quality of life, in an enjoyable and person-centered manner, which is specifically tailored to the individual's interest and motivation.

Funding

No funds, grants, or other support was received for the production of this manuscript.

Conflicts of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Acknowledgments

We would like to thank Tristian Mayglothing (University of Essex, School of Sport, Rehabilitation and Exercise Sciences) for their help in the replication of the screening process for the systematic review.

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