**The Non-Fitness-Related Benefits of Exergames for Young Individuals Diagnosed with
Autism Spectrum Disorder: A Systematic Review**

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Author Note

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Abstract

Background. *Autism Spectrum Disorder (ASD) is a common neurodevelopmental condition characterised by social-communication deficits and is often accompanied by an array of symptoms, 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 individuals diagnosed with ASD, exclusive of their effects on fitness-related/health-related outcomes.* **Methods.** *We systematically reviewed the literature for articles published between 1990 – 2020, which aimed to examine the effectiveness of exergames for targeting some of the symptoms observed in children diagnosed with ASD, exclusive of physical fitness-related outcomes.* **Results.** *Out of 193 relevant articles, 10 met the inclusion criteria. All studies showed 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 supports the use of exergaming to improve some functions in ASD and suggests future research is needed to expand on this for the enhancement of social-communication skills.*

Introduction

Autism

Autism Spectrum Disorder is a long-term neurodevelopmental condition accompanied by a markedly restricted repertoire of activities and interests and is diagnosed by profound social-communication impairments and difficulties with verbal and non-verbal communication (APA, 2013). The direct cause, or aetiology, of ASD is unknown. However, it is thought to derive from a multitude of genetic, biological, and environmental risk factors; suggesting a complex interplay between genes and the environment resulting in atypical development (Cheroni et al., 2020). Currently, the World Health Organisation (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 et al., 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 diagnosed with ASD¹ experience difficulties in social communication and interactions, alongside repetitive behaviours, it is increasingly recognised that autistic individuals show poor motor proficiencies and executive dysfunction. The available literature suggests that between 80 - 90% of autistic children exhibit some kind of motor impairment (Hilton et al., 2014). In comparison to their typically developing (TD) peers, those with 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 et al., 2004). For example, using the Henderson Test of Motor Impairment (Lam & Henderson, 1987),

¹ We, as authors, note the differing opinions for use of preferred language within the autistic community. Though the trend appears to slightly favour the identify-first language (i.e., autistic persons; Kenny et al., 2016), many individuals also prefer the use of person-first language (i.e., person with/person diagnosed with autism). Therefore, we have opted to use the terms interchangeably throughout the manuscript.

Manjiviona and Prior (1995) reported impaired movement in 67% of children diagnosed with ASD. Additionally, Green et al. (2009) assessed 101 children with ASD using the Movement Assessment Battery for Children (Henderson, 1992; Henderson et al., 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 somewhat impaired in autistic individuals (Demetriou et al., 2018). It is believed that EF difficulties have an important role in ASD. Arising from poor regional coordination and integration of prefrontal executive processes that combine emotion and social circuits, executive dysfunction may relate to some of the core symptoms associated with the disorder, such as social cognition and social impairments (Leung et al., 2016; Maximo et al., 2014).

Due to the complex symptomology, including social, cognitive, and motor differences and the vast heterogeneity of the disorder, there are no ‘treatments’ or interventions that successfully target all symptoms observed in ASD. Additionally, some autistic individuals do not want to be ‘treated’ as they see their diagnosis as an inherent part of their being – autistic is *who* they are (Vivanti, 2020). However, some individuals diagnosed with ASD may need help and support for certain activities or therapeutic intervention in order to improve their quality of life. Therefore, current research suggests that interventions should aim to target and reduce specific and functionally impairing symptoms associated with the disorder in a person-centred manner (Galpin et al., 2018; Nicholas et al., 2020; Therrien & Light, 2018).

Physical activity and exergames

Physical activity (PA) and exercise have been shown to have beneficial effects for young individuals diagnosed with ASD; alleviating some of the negative symptoms associated with the disorder. 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 et al., 1994). Despite the somewhat promising relationship between ASD symptomology and PA, individuals diagnosed with ASD 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 with autism are more likely to engage with video or computer games than other populations, with online gaming increasing from childhood to adolescence in autistic individuals (Engelhardt et al., 2017; Mazurek et al., 2012; Mazurek & Wenstrup, 2013). 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'. Exergames, which combine 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 undesirable symptoms associated with ASD, whilst also being engaging and enjoyable for many autistic individuals.

Previous research has indicated that exergames can be effective interventions for supporting developmental skills, including social, cognitive, and motor development, and rehabilitation in many different populations and clinical samples. Examples of this can be found in their use with TD individuals (Joronen et al., 2017), children and adults with cerebral palsy (Deutsch et al., 2008; Jelsma et al., 2013) or down syndrome (Perrot et al.,

2020; Silva et al., 2017), and individuals diagnosed with Parkinson's disease (Ribas et al., 2017). 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), research is attempting to 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 behaviours and improve fitness-related outcomes such as heart rate and calories burned (Fang et al., 2018; Finkelstein et al., 2013; Finkelstein et al., 2010; Hilton et al., 2015; Jozkowski et al., 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-recognised 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 negative 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 unwanted differences observed in ASD. In addition, we hope to provide a direction for future research to develop tailored exergame-based interventions for young individuals diagnosed with ASD that will support the development of communication skills, a core facet of ASD.

Methods

Research question

To provide a summary of the current evidence relevant to the non-fitness-related impacts of exergames for young individuals diagnosed with ASD and to investigate whether exergames and active videogames can elicit positive effects for autistic individuals, we utilised the PICO strategy to devise a central research question. PICO is a widely recognised 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 within-subject study designs, comparing the effects of an exergame by pre- and post-intervention tests, therefore we opted not to specify the inclusion of a control group or comparative intervention in our research question.

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”, “behaviour”, “effect*”, alongside the Boolean operators; “and” and “or”.

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).

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 individuals diagnosed with ASD	Included no individuals with a diagnosis of ASD
Published between 1990 and 2020	Published before 1990
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

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 et al., 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 utilised, 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 finalise articles to include for evidence synthesis (Figure 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 utilised, findings, and conclusions.

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

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-randomised 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.

Results

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% CI: 0.626 to 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 et al., 2017; Collins et al., 2015; Edwards et al., 2017; Flynn & Colon, 2016; Hilton et al., 2014). However, two were within-subject experimental designs with an A-B-A exposure (Anderson-Hanley et al., 2011; Chung et al., 2015), one

was a two-arm parallel single-blinded trial (Lau et al., 2020), and another was a mixed-methods observational study (Pope et al., 2019). Only one study included in this review was a randomised controlled trial (Rafiei Milajerdi et al., 2020).

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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	Conclusions
Anderson-Hanley et al., 2011	Autism and exergaming: effects on repetitive behaviours and cognition	A within-subject experimental design, with A-B-A exposure; 2 pilot studies (I & II)	<i>Pilot I</i> <i>N</i> = 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 minutes	Repetitive behaviours 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 Colour Trails Test and the Stroop Task	Statistically significant condition $\times$ time interactions were found for repetitive behaviours ($P < .001$, Digits Backwards ($P < .05$) and Stroop Task ($P < .05$). Repetitive behaviours 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 Colour Trails 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 groups was significantly different from the change in the control group revealing improvement after exergaming (for both DDR and cyber-cycling) compared with the control condition, for repetitive behaviours and at least one measure of executive function
			<i>Pilot II</i> <i>N</i> = 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 Colour Trails Test	Statistically significant condition $\times$ time interactions were found for repetitive behaviours ($P < .05$) and Digits Backwards ($P < .05$). Repetitive behaviours significantly decreased after cyber-cycling ($P < 0.05$), whilst performance on the Digits Backwards test improved ($P < 0.001$, compared with the control condition	

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Caro et al., 2017	Using the FroggyBobby exergame to support eye-body coordination development of children with severe autism	Repeated measures deployment study	<i>N</i> = 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 levels of FroggyBobby.	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 framework quantifying children's behaviours and interactions with the game; such as, emotional expression, attention, motor performance and prompts	Emotional expression: when expressing emotions (representing 30% of the total time of the game session), most of the time those emotions were positive (99%). Attention: on average, children were focussed in 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% ($P < .0001$)	The results indicate children with severe autism maintained positive emotions and their attention for the total duration of the therapy, reduced their aimless limb movements and developed aimed limb movements, as a result of weeks of usage of the exergame
Chung et al., 2015	Social Behaviours and Active Videogame Play in Children with Autism Spectrum Disorder	Single-case, within-subject experimental design, with an A-B-A exposure, observational study	<i>N</i> = 6; 4 males, 2 females; 6 - 12 years old (10.6 years old). 3 pairs of dyads, consisting of the 'target' child who has an ASD diagnosis and their sibling.	Kinect	Conducted within the home environment. Each dyad (ASD child + 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	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.	In ASD children who already played sedentary videogames, active video gaming did not sustainably improve the quality of social engagements with their siblings over sedentary video gaming.

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					based on Kinect active videogames, and then 2 control sessions again		Aggression was unchanged. All parents thought the active videogame sessions 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	<i>N</i> = 17 (13 due to drop out); 12 males, 5 girls; 8 - 18 years old (11.76 years old)	Makoto Arena	Conducted at the Clayton Child Centre 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 Behaviour 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 behavioural 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 children and adolescents with ASD
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	<i>N</i> = 30; ASD <i>N</i> = 11; 8 males, 3 females; 6 - 10 years old (7.64 years old); TD <i>N</i> = 19; 10 males, 9 females 6 - 10 years old (7.89 years old)	Kinect	ASD; conducted within the home environment for 2 weeks. Each child engaged in Kinect Sports Season 1/2 or Sport Rivals for 45-60 minutes, 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	Repeated measures pre- and post-test	<i>N</i> = 36 children; 25 males, 11	Wii	Participants were randomly assigned to playing alone or paired	Parents completed a demographic questionnaire, and both	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

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	Play Improves Executive Functioning More Than Collaborative Play for Children with Special Needs	experimental design	females; 7 - 18 years old; (12.31 years old) All children had cognitive, social, and emotional disabilities, with 34% having an ASD diagnosis		play conditions and then participated in the exergame Just Dance 4, dependent on the condition for on average 20 minutes.	children and parents completed a short media 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 ($p < .05$)	they played alone, they improved their executive function from pre- to post-intervention. The findings support previous studies that have shown that children with special 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 ASD.	Makoto Arena	Conducted at the Clayton Child Centre 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	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
Lau et al 2020	Effectiveness of active video game usage on body composition, PA level and motor proficiency in	Two-arm parallel, single-blinded trial	$N = 203$; Intervention $N = 125$; 92 male, 33 female, 8 - 18 years old (mean unknown);	Kinect	Conducted with a school setting for 12 weeks. Participants completed two 30-minute intervention sessions per week, playing Kinect Sport Season Series 1 and 2.	Body composition and PA level measured by ACTi Graph GT3X + activity monitor. Motor proficiency was measured by the BOT-2	Body composition increased for both groups. Children's BOT-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	Exergames were unable to improve motor proficiencies, body composition or PA levels over and above that of the control group

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	children with intellectual disability		Control $N = 78$; 54 males, 24 females, 8 - 18 years old (mean unknown). All had an intellectual disability; 51.2% had comorbid autism		Control group received no intervention and continued with PA as usual		< .01). However, this was not statistically significant between groups	
Milajerdi et al., 2020	The effects of PA and Exergaming on Motor Skills and Executive Functions in Children with ASD	Randomised 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 centre. 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 ($P < 0.05$), 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 ($P < 0.01$). 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 MS resulted in motor function improvement in children with ASD. Our findings also suggest that exergaming may improve EF in children with ASD; however, future research is warranted
Pope et al., 2019	Comparison of exergaming	Mixed methods	$N = 5$; all males; 5.5 -	Wii	Conducted within a school environment for	Sedentary behaviour, light PA and moderate-to-	Children had a high affinity for Just Dance 4. Exergaming	Exergames can increase levels of PA

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and adaptive physical education on PA, on-task behaviour and communication in children with ASD	observational study	10.5 years old (6.8 years old). All individuals had an ASD diagnosis	3 weeks. Each child completed three sessions of exergaming, specifically Just Dance 4 or Wii Sports, and Adaptive Physical Education (6 sessions in total)	vigorous PA measured via an accelerometer during each condition. Direct observations during each condition including coded on task and attentive behaviours and communication	condition had higher average minutes of MVPA and lower average of LPA. Direct observation revealed greater percentage of on-task behaviour during AdPE than exergaming and a high percentage of communication also seen in AdPE	and promote on-task behaviour and communication. However, in this study, AdPE was observed to be better at promoting on-task behaviour and communication than exergames
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(DDR; Dance Dance Revolution, ASD; Autism Spectrum Disorder, PA; Physical Activity, BRIEF; Behaviour 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)

Study Characteristics

Characteristics of participants

As this review focuses on the effects of exergaming for young individuals diagnosed with ASD, 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.

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 behaviours, 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 utilised the Kinect platform, requiring participants to complete up to 3 exergame sessions a week, for 12 weeks. However, Chung directed ASD children to play the Kinect-based exergame with their TD sibling in the home environment, whilst Lau asked ASD 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 utilised 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.

Characteristics of outcome measures used

The studies included in this review examined a variety of potentially beneficial outcomes of exergames for young individuals diagnosed with ASD 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 behaviours. 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 and 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 behaviours, Pope et al. (2019) and Chung et al. (2015) both videotaped their participants during intervention sessions, subsequently observing the tapes to score behaviours according to a coding manual and to assess changes in social behaviours.

Study Findings

Overall, most studies reported that exergaming produced several benefits for young individuals diagnosed with ASD. 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 and Hilton utilised the Behaviour Rating Inventory of Executive Function (BRIEF) to measure changes in EF and both observed improvements in all areas of the inventory. Collins reported a significant improvement in global executive composite ($P < .05$) and metacognition index ($P < .01$) and Hilton reported a significant improvement in the specific areas of working memory ($P < .05$) and global executive composite ($P < .05$). Rafiei Milajerdi 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 to 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.

Caro et al. (2017), Collins et al. (2015), and Hilton et al. (2014) all reported an improvement in motor skills. Caro 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 to 29.45 ± 3.91 , on the Pictorial Scale of Perceived Movement Skill Competence ($P < 0.05$), 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.

Chung et al. (2015) noted no substantial improvement in social behaviours, 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 behaviours, 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 $34.0\% \pm 11.8$ compared to $16.1\% \pm 10.1$ in the exergaming condition.

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 reported that on average all participants enjoyed their exergaming experience. Similarly, Chung et al. (2015) received parent feedback following their exergaming intervention inferring that the '*Kinect*' games were a positive and enjoyable experience, which was engaging and social for their children.

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 (Figure 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’.

Figure 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)

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Anderson-Hanley et al., 2011	●	●	+	●	+	+	?
Caro et al., 2017	●	●	+	+	+	+	●
Chung et al., 2015	●	●	+	?	+	+	+
Collins et al., 2015	●	●	+	●	+	+	+
Edwards et al., 2017	●	●	+	+	+	+	+
Flynn and Colon, 2016	+	+	+	?	+	+	+
Hilton et al., 2014	●	●	+	?	+	+	+
Lau et al., 2020	●	+	●	?	+	+	+
Milajerd et al., 2020	+	+	?	?	+	+	+
Pope et al., 2019	●	●	+	+	+	+	+

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 individuals diagnosed with ASD. These included improving EF, increasing motor proficiencies and, to some extent, promoting communication. Additionally, results from the studies included within this review suggest that participants enjoyed the exergames, which is a key component to helping ASD individuals engage with interventions (Finke 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.

Implications for practice and future work

Online media such as videogames and exergames are believed to be intrinsically motivating for many individuals diagnosed with ASD and, falling in line with the available literature, the results from this review suggest that exergames are engaging, motivating, and enjoyable for young individuals diagnosed with ASD (Caro et al., 2020; Finkelstein et al., 2010; Lyons, 2015). 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 individuals diagnosed with ASD.

Recognising 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 tasks presented in their everyday lives (Durkin et al., 2013). Previous studies have indicated that individuals with ASD play videogames for a variety of reasons, including emotional regulation, immersion, social interaction, achievement, creativity, and mental stimulation (Finke Erinn et al., 2018; Mazurek et al., 2015). Given that exergames are observed to elicit some beneficial effects, are intrinsically motivating, and enjoyable for individuals diagnosed with ASD, 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 programmes to improve EF and motor skills in autistic children.

Despite poor social and communication skills being a core diagnostic symptom 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 behaviours in young autistic individuals. Both Chung et al. (2015) and Pope et al. (2019) observed communication and social behaviours during their exergaming conditions. Chung et al. 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. Pope et al. noted an improvement in on-task behaviour 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, for social skills to be tested before and after the intervention and more robust 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 emphasises 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 et al., 2015; Camurri et al., 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 et al., 2016; Karkou et al., 2019), Parkinson's disease (de Natale et al., 2017; dos Santos Delabary et al., 2018), and autism (Scharoun et al., 2014; Takahashi et al., 2019). Importantly DMT has been observed to improve communication skills in young individuals diagnosed with ASD, with dance and movement therapists reporting promising results through the successful use of mirroring, synchronous movement interaction, and rhythm (Devereaux, 2012; Martin, 2014; Cozolino, 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 et al., 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 et al., 2020). Therefore, future work should attempt to evaluate the beneficial effects of dance-based exergames on the social skills of young autistic individuals utilising randomised 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), and/or coded observations in a given context (Heimann et al., 2006; Nadel et al., 2000; White et al., 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 social responsiveness scale, exergames could be more confidently integrated into practice for the development of social skills in the autistic population.

Limitations

Limitations within the studies included

Almost all of the studies included in this review presented promising results for improving a variety of domains within ASD. However, they are not without their limitations. Out of ten studies, only two included a control group; the first was a randomised 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-randomised 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 groups (Gerstein et al., 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 or familiarity with the assessments (Collins et al., 2015). To overcome this limitation and to confidently state exergames can elicit positive effects in young individuals with ASD, future studies should aim 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 utilised a within-subject design, as this was 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 et al., 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 with 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 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 et al., 2018; Movahedi et al., 2013). For example, Nicholson et al. (2011) demonstrated that antecedent PA was able to

improve academic engagement four weeks post-intervention and Bahrami et al. (2012) described behavioural gains that were maintained long-term (1 month), following a 14-week martial arts-based training programme in autistic children. As a result, future work may wish to explore the maintenance of improvements following exergaming by performing a follow-up assessment.

Conclusion

This systematic review collates the available evidence that suggests exergames may be a viable vehicle to elicit beneficial effects in young individuals diagnosed with ASD, exclusive of PA levels/fitness-related outcomes. Research suggests that exergames can reduce repetitive behaviours, 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 some 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. Such work may allow exergames to be integrated into clinical practice, where exergames are utilised to improve specific domains of ASD in an enjoyable and person-centred manner, which is tailored to the individual's interest and motivation.

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