Review Journal of Autism and Developmental Disorders (2023) 10:749–770
https://doi.org/10.1007/s40489-022-00319-5

REVIEW PAPER

Effects of Physical Activity on Social, Behavioral, and Cognitive Skills in Children and Young Adults with Autism Spectrum Disorder: a Systematic Review of the Literature

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Received: 6 August 2021 / Accepted: 5 April 2022 / Published online: 27 April 2022

Abstract

This systematic review aims to describe six types of physical activity interventions utilized with children and young adults ages 5–22 as a treatment for ASD. These interventions include swimming, cycling, neuromuscular training, yoga, sports, and exergaming. This examines the knowledge gaps regarding the details of these interventions via time (sessions, per week, overall length), the severity of ASD in participants (using a 4-point scale), and the outcomes specific to ASD (cognition, social skills, physical fitness, and behavior). A systematic search of peer-reviewed research articles was conducted across five databases focusing on physical activity as an intervention for children and young adults with ASD. From an initial screening of 387 records, 29 of the studies were included in the review. The analysis includes types of intervention, dependent measures, research design, and intervention duration. Types of intervention most studied (swimming, cycling, neuromuscular training, yoga, sports, and exergaming) were further analyzed. All studies found that physical activity as an intervention, improved aspects of physical fitness (endurance, strength, balance), cognition, social skills (language, eye contact, engaging with others), and/or behavior.

Keywords Autism spectrum disorder · Physical activity · Exercise · Quality of life

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disability that affects social communication and behavior development that typically is present from birth. According to the Diagnostic and Statistical Manual of Psychiatric Disorders, 5th edition (DSM-V) (American Psychiatric Association, 2013), common characteristics within the definition and associated with ASD include the following: (a) significant deficits in social communication and social interaction including social-emotional reciprocity, nonverbal communicative behaviors, the ability to develop and maintain relationships, and (b) limited and/or repetitive patterns of behavior, interests, or activities, including repetitive or stereotypical movement patterns or speech, insistence on sameness and strict adherence to routines, fixation in a few interests that are abnormal in intensity or focus, and hypersensitivity or hyposensitivity to sensory stimulation.

The Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) (2020) notes that there is currently no one standard treatment for children and/or young adults on the autism spectrum. The effectiveness of particular therapies and interventions is different for each child on the autism spectrum (DeFilippis & Wagner, 2016). NICHD lists several popular treatments for ASD including the following: (a) behavior management therapy, which includes applied behavior analysis (ABA) and positive behavioral support (PBS), (b) cognitive behavior therapy, which focuses on the connection between thoughts, feelings, and behaviors, (c) social skill training, (d) medication treatment, (e) nutrition therapy, and (f) speech, occupational and physical therapy. Often multiple therapies are administered in concert to help reduce common ASD characteristics and increase physical health.

Physical activity (PA) as a treatment alternative or complement to other treatments to improve social, behavioral,

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and academic skills in children and young adults with ASD is receiving new interest from parents and clinicians, and research supports PA as an effective treatment (Arnell et al., 2020; Tiner et al., 2021). In this review, PA is defined as moderate to vigorous exercise as suggested by prior research (Piercy et al., 2018). PA as an intervention has been shown to decrease extraneous motor behaviors (Fragala-Pinkham et al., 2011; Yilmaz et al., 2004), improve social skills (Castillo & Olive 2018; Fragala-Pinkham et al., 2011; Jimeno, 2019; Pan, 2010; Radhakrishna et al., 2010; Sotoodeh et al., 2017), and increase general fitness (Cristian, & Elsayed, 2019; Jimeno, 2019; Kozlowski et al., 2020; Lochbaum, & Crews, 2003; Pan, 2010; Yilmaz et al., 2004). What is more, a variety of PA programs have proven to be therapeutic (successful in decreasing negative symptoms) for those with ASD (Toscano et al., 2017). For example, Rosenthal-Malek and Mitchell (1997) found that the five participants with ASD in their single-subject study who participated in 20 min of jogging before doing academic work showed a significant decrease in self-stimulatory behavior and an increase in correct responding and the number of tasks completed.

Another finding in jogging was an increase in cognitive aspects (e.g., improved learning and academic success). For example, Oriel et al. (2011) found that aerobic exercise such as jogging, taking a brisk walk, or riding a bike immediately before academic work may improve academics (correct answers) in young children with ASD, although no significant differences were found for on-task or stereotypical behavior. Furthermore, Magnusson et al. (2012) found that high-intensity cardio and resistance exercise twice a week for one hour per session resulted in improved positive behaviors related to academic performance and social skills in six children with ASD.

There have been a handful of reviews of literature and meta-analyses summarizing the effects of PA on individuals with ASD (Bremer et al., 2016; Healy et al., 2018; Lang et al., 2010; Sam et al., 2015; Young & Furgai, 2016). For example, Young and Furgai (2016) wrote a brief review that found swimming, jogging, and trampoline had a positive effect on behaviors and social skills, but their review was very minimal and did not detail the characteristics of the studies. Two groups (Healy et al., 2018; Sam et al., 2015) conducted meta-analyses on the effects of exercise on individuals with ASD. While both meta-analyses examined factors such as intervention, sample, and study characteristics, analyses of these factors were statistical and did not provide detail that would be easily applicable to practice. Additionally, neither of these studies detailed the effects of PA on specific ASD characteristics such as deficits in behaviors, communication, and social skills.

The purpose of this study is to review the impact of PA on core symptoms associated with ASD for individuals 5 to 22 years of age. The review focuses on specific characteristics of these interventions including intervention type, research design, environment, sample, and symptom targeted. A synthesis of retrieved studies analysis and recommendations for future practices are presented. The overall goal of this review is to analyze what PA interventions are commonly used and supported by research; what severity of ASD is empirically shown to benefit from these interventions and extract enough detail of each intervention that they may be replicated by the general public and experts alike. This review seeks to close the research gap between interventions and the severity of ASD, as well as increase application of these empirical findings by the general public. To the best of the authors' knowledge, there are no other reviews that address the severity of ASD diagnosis and PA interventions. What is more, by including as much detail as possible about each PA intervention, it can be argued that parents of children and young adults with ASD have greater potential to replicate these interventions successfully on their own. Finally, by providing the severity of ASD diagnosis, parents and guardians will also have a better idea of if a PA intervention is appropriate for their dependent, and if there is empirical support for its use.

Methods

Search Criteria

This review utilizes a search that adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2015). The following are the databases that were searched for peer-reviewed articles: Pubmed, SagePub, SPORTDiscus, Elseiver, and JSTOR. Search categories include sample population, intervention, and outcome: (a) sample: autism, ASD, autistic; (b) intervention: exercise, cross-training, weightlifting, neuromuscular training, cycling, swimming, yoga, physical activity, and exergaming; and (c) outcomes: social skills, positive behaviors, endurance, strength, balance, cognitive function, and/or behavioral outcomes. Published reviews of the literature on PA and ASD are also included in the search but had to have been published in 2000 or later (this is discussed further below). References from found articles are also examined to determine if any studies were missed during the initial search.

Inclusion and Exclusion Criteria

To be included in the present review, studies had to meet three criteria. First, the study had to consist of at least one participant with an ASD diagnosis. Second, participants had to be 22 years old or younger. Third, the intervention had to be a form of PA (e.g., swimming, cycling, or yoga). To be included as a category of PA, the intervention had to meet the following criteria: there were at least four empirical studies within that category of intervention, and the research reported on outcomes related to ASD. Exclusion criteria include articles not available in English or not published in a peer-reviewed journal, and articles published before the year 2000. This year was used to encompass the most contemporary research that is most likely to be used and built upon by the field.

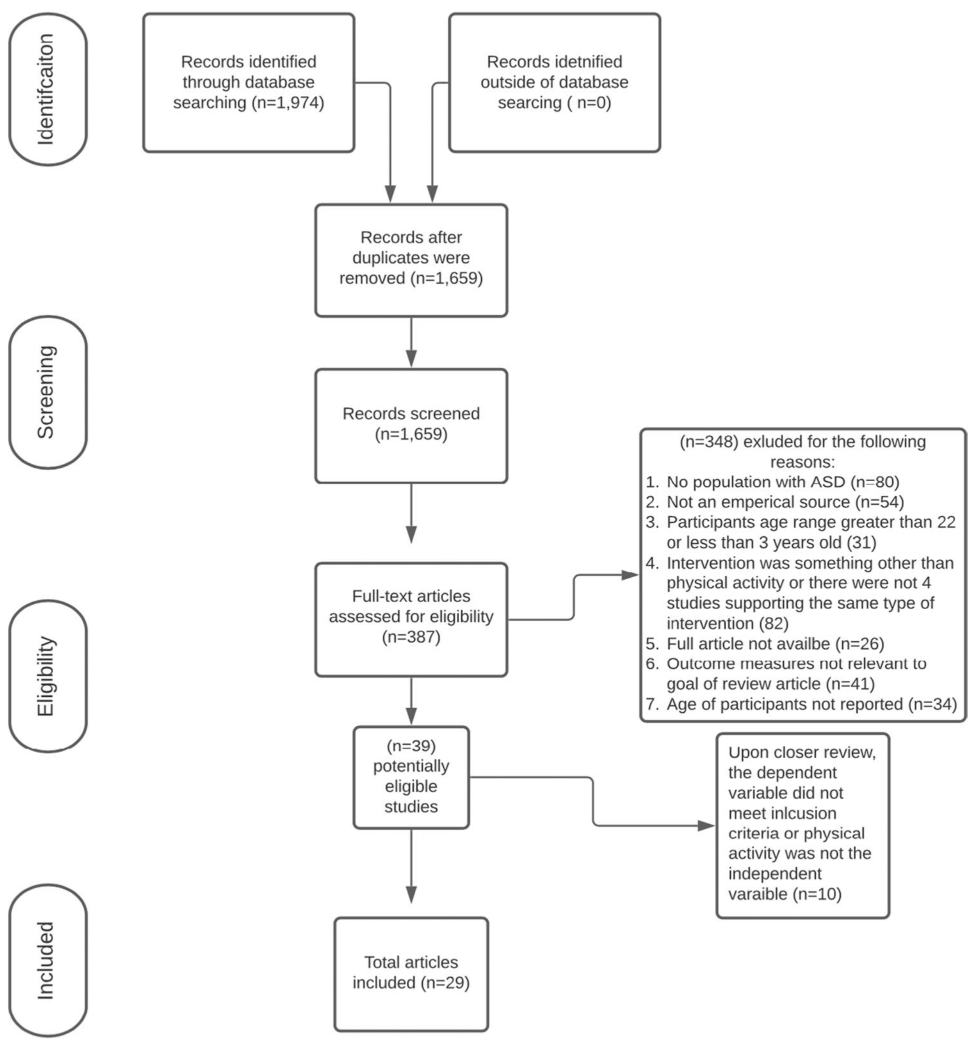
As seen in Fig. 1, an initial screening started with 1974 records. Of these records, 315 duplicates were removed. Many of these studies were excluded because they focused on teaching or pedagogy as an intervention, with PA being the dependent variable, or did not report outcomes related to a PA intervention ($n = 1272$). Other common excluding factors were not having a population with ASD ($n = 80$), not being of an empirical source ($n = 54$), not having at least four articles exploring category type ($n = 82$), the full article was not available ($n = 26$), the article did not report outcomes on previously deemed dependent variables (e.g., balance, aerobic-endurance, cognition) ($n = 41$), and age of participants was not reported ($n = 34$). From the remaining articles, 29 were found that focused on PA as an intervention in ASD with dependent measures including motor skills, social skills, cognition, balance, strength, behavioral outcomes, and aerobic endurance. From these studies, six categories for interventions were created: swimming, cycling, neuromuscular training, yoga, exergaming, and sports.

Collectively, 29 studies provided interventions to 632 participants with ASD. Of the studies that identified gender, 85% of the participants were male, and 14% were female. Importantly, only 34% of the cited articles specified the gender of their participants. The age range was 5 to 22 years of age. This age range was chosen to reflect the large period that an individual with ASD may be in the school system.

Data Extraction and Analysis

Using a data extraction based on the PRISMA statement for reporting systematic reviews, both authors (JH, MB)

Fig. 1 Data extraction and analysis



examined the studies included in this review for the following data: (a) study characteristics, measured independent and dependent variables; (b) intervention characteristics; and (c) participant characteristics (see Fig. 1 and the heading "Participant ASD Diagnoses").

Study Characteristics

When examining the studies for this review, the authors included quasi-experimental and experimental research, with quasi-experimental used when researchers were unable to use randomized groups. Both of these study types are empirically able to establish a cause-and-effect relationship. This was crucial to the present review, as it seeks to establish if there are effects (seen in the dependent variables) caused by PA interventions.

Independent and Dependent Variables

The independent variable that the authors were using as a guide for inclusion was PA interventions. PA was the theorized source of cause for the changes to the dependent variables being explored. Dependent variables included the following: social skills, motor skills, cognition (any measure, but commonly academic-related), balance, aerobic endurance, balance, strength, and behavioral outcomes. These dependent variables were decided on by the high frequency of their appearance in the literature regarding PA and ASD. Finally, to be included in this review the studies had to report sufficient statistical support for their conclusions (i.e., *t*-tests, bivariate correlations, one-way ANOVA).

Intervention and Participant Characteristics

The authors searched for PA interventions that served individuals with ASD, provided outcomes, were empirical in execution (meaning they were conducted by researchers), and provided sufficient detail on duration and type of PA. What is more, these interventions needed to also provide sufficient detail on the participants included. This was necessary as the authors of the current review sought to address the severity of ASD diagnosis, the amount of PA provided, and the outcomes of that intervention. Finally, there had to be at least four studies evaluating the same type of intervention for it to be included (this was to allow for sufficient exploration of outcomes related to the specific intervention and encompass more samples of individuals with ASD) (Tables 1, 2, 3, 4, 5, 6, and 7).

Table 1 Averages of weeks, sessions per week, and length of sessions per intervention

Activity	Avg. weeks of intervention	Avg. number of sessions per week	Avg. duration per session
Swimming	12	2	60 min
Cycling	3	4.5	55 min
NMT	8	3	55 min
Yoga	30	4	45 min
Sports	11	4	70 min
Exergaming	5	2	20 min

Participant ASD Diagnoses

All 29 of the studies consisted of participants with ASD. However, because the diagnosis of autism exists on a spectrum, each group of participants varied. To aid in examining the given research, a spectrum was created using a point system of 1 to 4 and a color code (see Table 8 legend), to better represent the participants and where they fell on the ASD spectrum (ranging from mild to severe). This information was given by each study, although most studies examined provided a broad diagnosis of participants, with only two studies (Yilmaz et al., 2004) giving specific insight into the ASD diagnosis of the given participants. As seen in Table 8, "mild to moderate" was the most common level of ASD seen in the research. This can be explained by most of the research including a certain level of IQ and no other major health risks for their inclusion criteria. Only three studies (Caro et al., 2017; Duffy et al., 2017; Schmitz Olin et al., 2017) included participants with severe ASD.

Neuromuscular training had the lowest severity of ASD (avg. 1.4), and cycling had the highest (avg. 3). Sports was the second highest (avg. 2.8), closely followed by gaming (2.75) (Table 8). Combined, the discussed research covered a broad range of ASD diagnoses.

The limited inclusion for more severe ASD might be explained by the researchers needing participants capable of the following instruction, and excluding diagnoses with comorbidities that would add a confound to the integrity of the results. This might be best exemplified by the neuromuscular training category, which had only "mild" or "mild to moderate" diagnoses. Given the higher skill needed to complete these interventions, a more severe diagnosis of ASD may have made participation difficult. In contrast, sports intervention had the highest severity of ASD. This could be explained by these sports not needing as high a skill level or instruction comprehension. There is also the influence of parents allowing their children to participate in interventions that may be perceived as more dangerous. As a result, if a child did have a more severe diagnosis of ASD, then parents might not be as likely to seek the intervention due to safety precautions. The specific tools (when provided by the researchers) and criteria can be found in Table 9. While some of the cited research was thorough in their diagnostics criteria and tools, 6 of the 29 studies (Bahrami et al.,

Table 2 Swimming as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Yilmaz et al., 2004	Quasi-experimental	Motor skills, aerobic endurance. Balance, behavioral outcomes	The child was led by an instructor through basic swimming skills. There was a demonstration component, followed by a manipulation component where the subject's body was manually moved through the movement/skill. The instructor followed the Halliwick Method of hydro-therapy, which has four phases: adjustment to water, rotations, control of movement in the water, and movement in the water	All tested aspects of fitness improved. What's more, this study also demonstrated that stereotypical autistic movements decreased. Outcomes were measured via fitness tests ($n = 17$) and included tests such as Peak VO2, sit and reach, and knee extension strength. These results were found via a basic pre-post comparison (no additional statistical detail was provided)
Pan, 2010	Quasi-experimental	Social skills, motor skills	The child was led by an instructor through specific skills in the water (skills came from the HAAR checklist). The intervention had four categories: floor activities, one-to-two instruction, group activities, and cool-down activities	Male participants improved their fitness based on endurance, as well as increased positive behaviors such as sociability and social skills. What's more, this study demonstrated that water exercise swimming programs (WESP) in particular improved social skills and overall aquatic skills compared with the control group. Outcomes were measured via the HAAR checklist (motor skills) and the School Social Behavior Scales (social skills). These findings are supported by t-tests (for social skills) and a two-way ANOVAs (motor skills) at an alpha of 0.001
Lawson, & Little, 2017	Quasi-experimental	Social skills, behavioral outcomes	This intervention incorporated a sensory assessment into their aquatic therapy. This study served to analyze the change in sleep behaviors of children with ASD. Each participant received a sensory evaluation and individualized programming for aquatic therapy	Sensory enhanced aquatic exercises improved sleep behavior in children with ASD. The results of the study suggest that children with ASD who are prone to hyperarousal will benefit from this intervention as their sleep disturbances may decrease. Outcomes were measured via demographic form, social responsiveness scale, sensory profile caregiver questionnaire, children's sleep habit questionnaire, and parent satisfaction questionnaire. These findings are supported by *t*-tests at an alpha of .05
Ennis, 2011	Quasi-experimental	Social skills, motor skills, behavioral outcomes	Followed two cycles of a 10-week swimming intervention in ASD. Each session lasted 60 min, with a 5–10-min warm-up, followed by 7 activities, each lasting 5 min. Lastly, there were 10 min of free play at the end. Family participation was expected, as another goal of this intervention was to create an environment where families could participate in the community with their children	Increase in positive behaviors, and improved physical function. There was an increase in sociability and communication, and some participants (3) demonstrated an increase in academic performance. Participants that participated in both 10-week cycles, demonstrated significant improvement in the second cycle as well. These findings were supported by changes in Peds-QL scores and WOTA (a water skill test). No other further statistical detail was provided

Table 2 (continued)

Author(s)	Experimental design	Dependent variables	Methods	Results
Shams-Elden, 2017	Quasi-experimental	Motor skills	A 10-week swimming intervention was used, with 3 sessions weekly. The intervention used Halliwick-therapy specifically, implementing aquatic exercises. There were three phases: (1) mental adjustment and detachment, (2) control and balance, and (3) independent swimming	The results showed that the intervention significantly improved motor skills measured by a 20-m run, standing broad jump test, mushroom float, and walking in the pool. The CARS test was also used to evaluate ASD ratings. These findings are supported by paired *t*-tests at an alpha of 0.05
Fragala-Pinkham, et al., 2011	Quasi-experimental	Strength, aerobic-endurance	Included warm-up and aerobic activities (i.e., jumping jacks, jogging in place); strengthening activities (i.e., hip flexion bilaterally while supported by noodle), and cool down with stretching (i.e., marching in place in water)	The study found that there was an increase in social skills, balance, strength, and endurance. There was also some decrease in stereotypical autistic behaviors. Measures used were: Swimming Classification scale, YMCA Water Skills checklist, M-PEDI (mobility), and satisfaction questionnaire. These findings are supported by independent *t*-test and paired *t*-tests at an alpha of 0.05

2012; Caro et al., 2017; Ennis, 2011; Hilton et al., 2014; Lochbaum, & Crews, 2003; Schmitz Olin et al., 2017; Radhakrishna et al., 2010; Shams-Elden, 2017) did not provide much information other than the participants having a diagnosis of ASD. It is noted that in instances (when researchers were using convenience samples) that the diagnostic criteria were to have an ASD diagnostic on record with the school or institution (without reference to the severity of comorbidities). Due to this simplification, the variety of ASD diagnoses represented in these works cannot fully be explored.

Results

Interventions Used and Settings

Six of the studies (20%) used swimming as an intervention. Yilmaz et al. (2004) used a setting in a local swimming pool, with an experienced instructor. There was a demonstration component, followed by a manipulation component where the subject's body was manually moved through the movement/skill. Pan (2010) used a similar setting (a public location with a trained instructor), but focused on specific skills within the water, and also outside the pool. This intervention also had a group component. Lawson and Little (2017) and Shams-Elden (2017) held their intervention in a community pool, with a specialized therapist leading the participants. These interventions focused on sensory assessments and were individually programmed for each participant. Ennis (2011) conducted an intervention that took place in a community setting, with family participation. This intervention also incorporated free-play into the program, while still teaching new aquatic skills.

Four studies (13%) used cycling as an intervention. Ringenbach et al. (2015) used a specialized recumbent stationary bike (Theracycle) that had an electric motor to aid participants in pedaling. This occurred in a lab setting with participants all using the same equipment that was adjusted to their specific needs for the most efficient use. Castillo and Olive (2018) performed their intervention at the Paidea School (a special education school in Barcelona). Tutors, teachers, club managers, and family members were present to help with the intervention and ensure students were engaged and active. Schmitz Olin et al. (2017) used an aerobic-based intervention with stationary biking or walking on the treadmill. This took place in a school-environment gymnasium. The behavioral measurements occurred in a familiar classroom to the student. Hauck et al. (2014) taught adolescents with ASD how to ride a two-wheel bicycle, in an assessment of PA as an intervention on BMI and strength in ASD. The setting was in a school gymnasium and moved to the school parking lot if enough skill was acquired.

Table 3 Cycling as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Ringenbach et al., 2015	Experimental	Behavioral outcomes, cognition	The intervention was completed on a specialized recumbent stationary bicycle which had an electric motor to aid in pedaling. The power output of the participants was measured via an SRM PowerMeter. Participants were seated for 5 min, and then completed 20 min of biking followed by a 5-min cooldown	Results indicate that chronic ACT intervention is necessary for the best results. Their work demonstrated positive changes in behavior, such as improvement in inhibition as well as an increase in cognitive planning. Outcomes were measured via the CARS-P test, PPVT-IV, the Exercise Perception Scale, and an Off-Task Behavior Assessment. These results were supported statistically via t-tests at an alpha of .05
Schmitz Olin et al., 2017	Quasi-experimental	Aerobic-endurance, behavioral outcomes	Participants underwent five separate days of treatments. This included a control condition, a low-intensity 10-min condition, a high-intensity 10-min condition, a low-intensity 20-min condition, and a high-intensity 20-min condition. The intensity was quantified using HR and RPE. Before and 60 min after exercise, the frequency of stereotypic behaviors was measured	The results found that high-intensity aerobic exercise, such as biking, may exacerbate stereotypic behaviors in children with ASD. However, low- to moderate-intensity exercise produced significant reductions in these behaviors. This provides a cost-effective way to positively impact these individuals. Outcomes were measured via the OMNI scale (measuring exertion), and SSB assessments (measuring behavior). Statistical support for this work using pairwise comparisons and univariate analysis with an alpha of 0.05
Castillo & Olive, 2018	Quasi-experimental	Social skills, motor skills	The intervention included participation from each subject's tutor(s) and parents and focused on how to learn to ride a bike. The intervention had three phases: observation (assessing motor skills and abilities), interaction (transitioning from interacting with teachers only to interacting with the whole group), and outcomes (consisting of an intensification phase and overall analysis)	An increase in social skills, self-confidence, and motor skills (increase in endurance and balance) were found after the intervention. Outcomes were measured for motor skills with motor assessments on the bike, a checklist of technical aspects for cycling, and a diary session recording motor skill progression. Social skills were measured via social maps, parents and professional interviews, and diary sessions recording social skill progression. Due to the social measures being the main focus of outcome analysis, the statistical support is limited to basic observations in pre-post behavior via social maps and sociograms

Table 3 (continued)

Author(s)	Experimental design	Dependent variables	Methods	Results
Hauck et al., 2014	Quasi-experimental	Strength, balance	Measures of bilateral leg extension and flexion strength, bilateral standing balance, and BMI percentile were measured at baseline at 1 year following the intervention. On the Last day of the biking intervention, participants were classified as either riders or nonriders based on their ability to independently ride a distance of 100 ft or more	The study found that bicycle riding is associated with improved physiological outcomes in ASD and DS. This was including greater leg strength and reduced BMI percent 1 year following the acquisition of the skill. These results are significant, suggesting long-term strength and body composition outcomes for adolescents given biking as an intervention in ASD. Outcomes were measured via the Functional Movement Screen (FMS) and supported statistically with a two-sample t-test at an alpha of 0.05

Four studies (13%) investigated neuromuscular training as an intervention in ASD. Kozlowski et al. (2020) held a high-intensity exercise intervention in a gym setting. Trained staff members were leading the participants in each session, and it was in a group setting. Shavikloo and Norasteh (2018) utilized an integrative neuromuscular training intervention, with emphasis on movements to increase functional balance. The study occurred in a gym setting located within a lab. Lochbaum and Crews (2003) used a gym setting with a variety of equipment. Cristian and Elsayed (2019) executed their study in a physical therapy room where trainers administered the program. Jimeno (2019) utilized a clinic in a multidisciplinary pediatric private practice where there was a large gymnasium within the clinic that was used in this study.

Five studies investigated the use of yoga (17%) as an intervention in ASD. Radhakrishna et al. (2010) used an outdoor setting, with the child and parent present for each session. The goal was to create a serene environment for yoga intervention. Narasingharao (2017) used a structured yoga program as an intervention. The setting was at the special education school, Academy for Severe Handicap and Autism (ASHA). Sotoodeh et al., (2017) performed their intervention in the homes of the participants, with caregivers and parents leading the instruction. Detailed instructions were provided for them to use. Koenig et al. (2012) created a yoga intervention that occurred in the school setting. Each morning the classroom would participate in video instruction. Finally, Kaur and Bhat (2019) utilized a yoga intervention within a physical therapy program. This intervention occurred in a physical therapy setting.

Five studies used sports and games as interventions (17%) (Bahrami et al., 2012; Cai et al., 2020; Duffy et al., 2017; Gabriels et al., 2015). One took place outside at a college campus (Duffy et al., 2017) and around the surrounding area. Another took place in a school gymnasium (Cai et al., 2020), two took place on a farm (Bass et al., 2009; Gabriels et al., 2015), and one took place in a karate studio (Bahrami et al., 2012).

Four studies used exergaming as an intervention (13%) (Anderson-Hanley et al., 2011; Caro et al., 2017; Hilton et al., 2014). Two of these studies took place in a lab setting to use the proper gaming equipment (Caro et al., 2017; Hilton et al., 2014). The other two occurred in physical therapy rooms (Anderson-Hanley et al., 2011; Peña et al., 2020).

Dependent Measures

Between the 29 articles studied in this review, there were seven prominent dependent variables: motor skills, social skills, strength, aerobic endurance, balance, behavioral outcomes, and cognition. Eleven studies analyzed motor skills, with 4 being swimming-focused (Ennis, 2011; Pan, 2010; Shams-Elden, 2017; Yilmaz et al., 2004), one

Table 4 Neuromuscular training as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Jimeno, 2019	Quasi-experimental	Social skills, motor skills, cognition	The intervention was created by an exercise physical trainer and an educational and developmental psychologist. Components included aerobic exercises, bodyweight training, and social skill development all tailored to the participants. All physical exercises were founded on functional and cardiovascular fitness. Psychological techniques were implemented to foster social mannerisms, group skills, and to modify negative behaviors. Each exercise session implemented new skills and included a workout utilizing this skill	It was demonstrated that neuromuscular training can benefit overall fitness, psychosocial functioning, emotional regulation, social skills, and possibly cognition function. Outcomes were measured via the Pediatric Quality of Life Inventory 4.0. Statistical support was found using the Reliable Change Index (RCI) at an alpha of 0.05
Shavikloo and Norasteh, 2018	Experimental	Balance	This intervention was specifically designed for primary school children. The intervention consisted of a 5-min dynamic warm-up, five primary exercises that were centered on muscular power, lower body strength, and core strength, and secondary exercises that were centered on improving functional movement (i.e., balance and object control)	The integrative neuromuscular intervention significantly improved balance and posture. Specifically, three excursions were found to be benefited: anterior, posteromedial, and posterolateral. Outcomes were measured via the Gilliam Diagnostic Index. Statistical support was provided by a 2×2 ANCOVA (group × intervention) at an alpha of 0.05
Cristian & Elsayed, 2019	Quasi-experimental	Aerobic-endurance, balance	The integrative neuromuscular training program mainly focused on functional balance. Meaning, activities like sitting and getting out of a chair, standing with eyes closed, picking something up off the ground, being able to move without risk of falling, and more. The purpose of this intervention was to provide progressions of activities that enhanced proprioception and functional balance control	Demonstrated that functional balance was significantly improved as well as endurance. In theory, this intervention gave the participants more independence in their daily life activities through an improvement in balance and overall fitness. Outcomes were measured via the Pediatric Balance Scale (PBS), and results were analyzed via a one-way ANOVA at an alpha of 0.05
Lochbaum & Crews, 2003	Quasi-experimental	Aerobic-endurance, strength	The intervention consisted of an aerobic-based group and a strength-training group. The aerobic group was moderate intensity (65–70% of HR maximum) on a stationary bike for 20 min. The strength-training group consisted of 6 upper-body movements, and 6 lower-body movements focused on strength. The group completed 3 sets of 12 repetitions at 60%, then 3 sets of 6–8 reps at 80–85%. In both groups, participants were rewarded verbally	In the aerobic intervention, there was a range of increase between 33 and 50%, and with the muscular strength training, all exercises saw an increase between 12 and 47%. Therefore, both interventions improved physical fitness in ASD. Outcomes were measured via power work capacity and a one-rep max. Statistical support was provided via pre-post analysis (no further detail was provided)

Table 4 (continued)

Author(s)	Experimental design	Dependent variables	Methods	Results
Kozlowski et al., 2020	Quasi-experimental	Balance, aerobic endurance, strength	The intervention was highly-structured and consisted of a group setting with 12 children. The program was centered on a range of fitness targets: cardiovascular, endurance, strength, stamina, flexibility, balance, coordination, speed, agility, power, and accuracy. Each skill was addressed at least once a week. There was an instruction period of 5 min, a warm-up of 7–10 min, a workout lasting 15–20 min, a related game-play of 15–20 min, and a cool-down lasting 5 min	Suggest that a high-intensity exercise intervention promoted higher physical activity levels, overall fitness, and work productivity. Outcomes were measured via questionnaire, biometric measures (i.e., height, weight), exercise performance measures (i.e., GT3X Actigraph accelerometer), and a one-rep max. Statistical support was found using a paired *t*-test at an alpha of 0.05

cycling focused (Castillo & Olive, 2018), one neuromuscular focused (Jimeno, 2019), two yoga focused (Kaur, & Bhat, 2019; Koenig et al., 2012), three exergaming focused (Cai et al., 2020; Hilton et al., 2014; Peña et al., 2020), one sport-focused (Duffy et al., 2017). Ten studies analyzed social skills, with three being swimming-related (Ennis, 2011; Lawson and Little, 2017; Pan, 2010), one being cycling-focused (Castillo & Olive, 2018), one neuromuscular (Jimeno, 2019), three yoga focused (Koenig, et al., 2012; Radhakrishna et al., 2010; Sotoodeh, et al., 2017), and three sport-related (Bass et al., 2009; Cai et al., 2020; Gabriels et al., 2015). Seven studies analyzed strength as a variable, with two focusing on swimming (Fragala-Pinkham et al., 2011; Yilmaz et al., 2004), one cycling focused (Hauck et al., 2014), two neuromuscular focused (Lochbaum, & Crews, 2003; Kozlowski et al., 2020), two exergaming focused (Caro et al., 2017; Hilton, et al., 2014), and one sport-focused (Cai et al., 2020). Aerobic endurance was studied in five papers, one being swimming-oriented (Fragala-Pinkham et al., 2011), one being cycling (Schmitz Olin et al., 2017), and three neuromuscular (Cristian, & Elsayed, 2019; Lochbaum, & Crews, 2003; Kozlowski et al., 2020). Balance in participants was also measured in seven studies, with one being swimming-focused (Yilmaz et al., 2004), one being (Hauck et al., 2014), three being neuromuscular (Cristian, & Elsayed, 2019; Kozlowski et al., 2020; Shavikloo and Norasteh, 2018), and two yoga (Narasingharao, 2017; Radhakrishna et al., 2010). Behavioral outcomes were measured in 12 studies, three focusing on swimming (Ennis, 2011; Lawson and Little, 2017; Yilmaz et al., 2004), two in cycling (Schmitz Olin, et al., 2017; Ringenbach, et al., 2015), four in yoga (Koenig et al., 2012; Narasingharao et al., 2017; Radhakrishna et al., 2010; Sotoodeh, et al., 2017), three in sport (Bahrami et al., 2012; Duffy et al., 2017; Gabriels et al., 2015), and one in exergaming (Anderson-Hanley, et al., 2011). Finally, seven studies measured cognition, with one cycling study (Ringenbach et al., 2015), one neuromuscular study (Jimeno, 2019), three exergaming studies (Anderson-Hanley et al., 2011; Caro et al., 2017; Hilton et al., 2014), and two sport-related studies (Duffy et al., 2017; Gabriels et al., 2015).

Research Design

Of the 29 studies analyzed in this review, 24 were quasi-experimental with non-randomized grouping (Anderson-Hanley et al., 2011; Bahrami et al., 2012; Cai et al., 2020; Castillo & Olive, 2018; Cristian, & Elsayed, 2019; Duffy et al., 2017; Ennis, 2011; Fragala-Pinkham et al., 2011; Hauck et al., 2014; Hilton et al., 2014; Jimeno, 2019; Kaur, & Bhat, 2019; Koenig et al., 2012; Kozlowski et al., 2020; Lawson, & Little, 2017; Lochbaum and Crews, 2003; Narasingharao, 2017; Schmitz Olin et al., 2017; Pan, 2010;

Table 5 Yoga as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Koenig et al., 2012	Quasi-experimental	Behavioral outcomes, social skills	The intervention was a specific program called Get Ready to Learn (GRTL)which teaches yoga in a classroom setting. Teachers for each classroom received a GRTL program DVD, instructional materials, and yoga mats. Control and test groups completed the ABC-community questionnaire (targeting behavior). The DVD was played on a TV in front of all the students and provided visual and verbal cues. The program begins with establishing a quiet state, then breathing exercises, physical postures and exercises, and deep relaxation. Postures were in a developmental sequence	This study showed that yoga can decrease negative behaviors, such as irritability, lethargy, social withdrawal, hyperactivity, and noncompliance. The researchers also reported that the children were able to learn the yoga movements and routines satisfactorily. Measures included the Vineland Adaptive Behavior Scale-II, and statistical testing was conducted using a one-way ANOVA with an alpha of 0.05
Sotoodeh et al., 2017	Experimental	Social skills, behavioral outcomes	The intervention consisted of a step-by-step guide for parents and caregivers, and certified yoga instructions demonstrated each pose and watched the participants perform the pose. What is more, the instructors showed the poses via a computer as well to encourage engagement in the program	Results showed that there was an increase in social skills, cognitive and sensory awareness, and a decrease in stereotypic behavior associated with ASD. Outcomes were measured via The Autism Treatment Evaluation Checklist, and statistical support was conducted with an ANOVA and ANCOVA at an alpha of 0.05
Narasingharao, 2017	Quasi-experimental	Balance, behavioral outcomes	A structured yoga program was used. The yoga intervention was prepared by researchers. The practices were selected from S-VYASA Integrated Application of Yoga Therapy (IAYT) and yoga modules used in Arogyadhama for different ailments and Bihar School of Yoga	Reduction in aggression and self-harm behavior, as well as balance and sleep quality. Outcomes were measured via a 61-item questionnaire, and statistical support was found using a Wilcoxon singed rank-test
Radhakrishna et al., 2010	Quasi-experimental	Behavioral outcomes, balance, social skills	The intervention was yoga-based, with components focused on improving cognition, social skills, and communication skills. The program involved a warm-up, strengthening exercises, loosening exercises, calming asanas, breathing work, and chanting	There was a reduction in agitation and self-injurious behavior. An increase in balance, eye contact, and social skills increase endurance in sitting tolerance, balance, and depth perception, as well as in body posture. Outcomes were measured via a questionnaire and assessment created by the researchers. Statistical support was illustrated, but not specifically reported (showing a change in pre to post)
Kaur & Bhat, 2019	Quasi-experimental	Motor skills	The intervention was 4 sessions a week with either 2 parents or 2 experts present. Each intervention lasted 40 to 45 min (with experts) or 20 to 25 min (with parents). Parents were provided with DVDs to aid their training sessions with their children. Examples of yoga poses used are tree pose, frog pose, and bridge pose	The study found that after 8-weeks of intervention the test group had significantly improved in gross motor performance. Outcomes were measured via the Bruininks-Oseretsky Test of Motor Proficiency-2nd Edition, and the Stanford-Binet Intelligence scales (5th edition). Statistical support was found using a repeated-measures ANOVA and dependent *t*-test

Table 6 Sports as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Cai et al., 2020	Quasi-experimental	Social skills, motor skills, strength	A 12-week basketball training program was conducted in preschool children. The participants were in preschool (ages 3–6) and had ASD. There were three phases: (i) increase interest in basketball while introducing basic classroom rules to participants, (ii) basic basketball skills, physical fitness, and peer conditioning (i.e., making eye contact while passing), and (iii) basketball group games	The results of this study found that the basketball training camp promoted agility and strength. What's more, the findings suggest that there was an increase in social skills. Outcomes were measured via the SRS-2, CSHQ, CEBQ, and physical tests were conducted. Statistical support was found using a repeated-measures ANOVA at an alpha of 0.05
Duffy et al., 2017	Quasi-experimental	Behavioral outcomes, cognition, motor skills	A running "Monday Club" founded by the Saracens Sports Foundations was used as an intervention in behavior. The intervention lasted 16 weeks, meeting twice a week for 2 h	The results suggest that the running intervention approached a significant change on a variety of variables: emotional response, repetitive behaviors, and cognition. There were minor improvements, but not enough to say with certainty that the running club was responsible. Outcomes were measured via the GARS-3 scale, and statistical support was found using a t-test with an alpha of 0.05
Gabriels et al., 2015	Experimental	Behavioral outcomes, social skills, and cognition	Utilized a 10-week horseback riding intervention with a minimum of 45 min session duration. Each session had 2–4 participants, had equine-related information content, and there was at least one volunteer assigned to each participant. Instructors used behavioral teaching methods commonly used for the ASD population (e.g., use of visual aids, praise, and participant interests). There were 2 skills taught: therapeutic riding skills (i.e., trotting, steering, mounting), and horsemanship skills (i.e. caring for the horse). Each session followed the same schedule of putting on a helmet, waiting on a bench, mounting the horse, riding activities, dismounting, grooming the horse, and putting away equipment	The results of the study found that there was a significant decrease in irritability ($p = .02$) and hyperactivity ($p = .01$). What is more, the test group also demonstrated a significant improvement in social cognition ($p = .05$) and communication ($p = .003$). Outcomes were measured via the Peabody Picture Vocabulary Test (4th edition), Bruininks-Oseretsky Test of Motor Proficiency (2nd edition), the Vineland Adaptive Behavioral Scales (2nd edition), and a survey Interview form for caregivers. Statistical support was found using an independent *t*-test and chi-square test
Bass et al., 2009	Experimental	Social skills	The trained instructors assisted the participants in mounting and dismounting their horses. These actions were verbalized to participants. This segment of the program lasted 5 min and was aimed at stimulating verbal communication, proprioception, and vestibular processing. Next was 15 min of riding skill work (i.e., walk, trot, and halt), followed by 20 min of obstacle work (guiding the horse around poles). Afterward, the participants took part in grooming and caring for the horse	Participants in the experimental group demonstrated significant improvement in focus ($p < 0.001$), social responsiveness ($p = 0.038$). In general, compared to the control group, autistic children in the experimental group improved in sensory integration, directed attention, social motivation, and sensory sensitivity. Outcomes were measured via the social responsiveness scale and sensory profile. Statistical support was found using an ANOVA with an alpha of 0.05

Table 6 (continued)

Author(s)	Experimental design	Dependent variables	Methods	Results
Bahrami et al., 2012	Quasi-experimental	Behavioral outcomes	A martial arts intervention was utilized, specifically using Kata techniques. For 14 weeks 4 times a week, the children participated in the intervention	The children were assessed post-intervention (14 weeks), as well as a month post-intervention. The results indicate that Kata training significantly decreased stereotype behavior in the exercise group. After participating in Kata techniques training, stereotypy decreased from baseline levels by an average of 42.54% across participants. What is more, after 30 days of no practice, stereotypy in the exercise group remained significantly decreased. Outcomes were measured via Gilliam Autism Rating Scale (2nd edition), and through an independent *t*-test, a paired *t*-test, and 2-factor mixed-model ANOVA (all with an alpha of 0.05)

Shams-Elden, 2017; Radhakrishna et al., 2010; Peña et al., 2020; Yilmaz et al., 2004). Four of the studies were experimental, with randomized controlled groups (Bass et al., 2009; Gabriels et al., 2015; Ringenbach et al., 2015; Shavikloo and Norasteh, 2018; Sotoodeh, et al., 2017). The majority being quasi-experimental can arguably have to do with using participants who have ASD. This population can be difficult to randomize due to limited participants available, and of course, ASD is a non-random variable/criterion.

Intervention Duration

Twenty-four out of the 29 studies (82%) analyzed utilized interventions that lasted on average 11-weeks, with an average of 3.2 sessions per week, and an average of 50 min per session. On average, swimming interventions lasted 12 weeks, with two sessions per week, each for 60 min. Swimming and exergaming tied for the lowest average of sessions per week (see Table 1). Cycling interventions lasted an average of 3 weeks, with 4.5 sessions per week, each lasting 55 min. Cycling had the lowest weeks of intervention but did have the highest number of sessions per week on average. Neuromuscular training lasted an average of eight weeks, with three sessions per week, each lasting 55 min. Yoga interventions averaged 30 weeks, four sessions per week, and 45 min for each session. Yoga had the highest week average amongst all the interventions. The sports interventions averaged 11 weeks, with four sessions per week, and an average of 70 min per session. This was the highest average duration per session among all the interventions. Exergaming as an intervention had 5 weeks on average of intervention length, two sessions per week, and sessions lasted on average 20 min. All around, exergaming had the lowest averages for each category (tied with swimming for sessions per week) (see Table 1 for a summary).

Discussion

This systematic review aimed to describe five exercise interventions utilized with participants ages 5–22 as a treatment for ASD, including swimming, cycling, neuromuscular training, yoga, and exergaming. It is interesting to note that while the research analyzed in this review is empirical and novel, there is a lack of inclusiveness. The studies in this review all had participants with ASD in an environment without typically developing children and/or young adults. None of the interventions were tested within an inclusive environment, which has been shown to support the development of motor skills (Hutzler & Margalit, 2009; Sansi et al., 2020) and social skills (Sansi et al., 2020). Ennis (2011) did provide an environment within a community setting, which could have been inclusive, although this specific aspect was

Table 7 Exergaming as an intervention

Author(s)	Experimental design	Dependent variables	Methods	Results
Peña et al., 2020	Quasi-experimental	Motor skills	The "circus in motion" game was used as an intervention over 4 days for 30 min. This was coupled with traditional vestibular therapy to see if the exergame could be used as an additional tool to traditional therapy	The study found that using the game "circus in motion" was beneficial to therapy. The therapists reported that the children were more engaged and participated more willingly than in a traditional therapy session. The time of positive emotions was higher in the exergame (13.54%) than in traditional therapy (3.12%). What is more, 66.67% of participants performed more repetitions without a prompt than in traditional therapy. Outcomes were measured via a psychologist's observations during vestibular therapy, recorded video, and the CARS scale. Statistical support was found using the algorithm of the computer game system
Anderson-Hanley et al., 2011	Quasi-experimental	Cognition, behavioral outcomes	The cyber cycling intervention occurred over two pilot studies, each lasting 10 weeks. Participants completed 2 sessions per week for 20-min. The video game was either Dance Dance Revolution or a cyber cycling game	The results of the study found that cyber cycling significantly improved repetitive behaviors ($p = 0.03$) and the digits backward ($p < 0.001$). Dance Dance Revolution also demonstrated significant improvements in behavior ($p < .001$) and in the digits backward test ($p = 0.04$). Outcomes were measured via the GARS-2 scale and video replay. The statistical support was found using an ANOVA with an alpha 0.05
Caro et al., 2017	Quasi-experimental	Motor skills, cognition	A 7-week intervention using a game called FroggyBobby. The aim was to create a stimulus that allowed the player to practice aimed body movements, and reduce unnecessary movement. The game required movement patterns and motor skills	The study found that after 7 weeks, the participants who had severe autism and a significant increase in motor coordination. What is more, the findings also suggest that these children were able to focus for long lengths of time during therapy that utilized the game. Outcomes were measured via video replay and psychotherapist interview. Statistical support was found using a mixed model approach (affinity diagraming and sequential analysis techniques)
Hilton et al., 2014	Quasi-experimental	Motor skills, strength, cognition	A 30-session gaming intervention (Makoto arena) was conducted, with each session lasting 2 min (three times a week). This game is based on light and sound speed, challenging the response speed of the player	The study found that after 30 sessions, children with ASD (ages 6–13) increased their motor skills, strength, and also working memory. Outcomes were measured via the Behavior Rating Inventory of Executive Function (BRIEF) and the BOT-2. Statistical support was conducted via *t*-tests with an alpha of 0.05

Table 8 Demographics of participants

Author	Activity	n	Age Range	Gender *n*	ID	Severity
Yilmaz et al., 2004	Swimming	1	9	N/A	S1	1
Pan, 2010	Swimming	16	6-9	male (16)	S2	1
Lawson & Little, 2017	Swimming	10	5-12.3	male (10)	S3	3
Fragala-Pinkham et al., 2011	Swimming	12	6-12	N/A	S4	2
Shams-Elden, 2017	Swimming	10	N/A	N/A	S5	2
Ennis, 2011	Swimming	6	3-9	N/A	S6	2
					Swim Avg	1.8
Hauck et al., 2014	cycling	25	n/a	N/A	C1	3
Olin et al., 2017	Cycling	7	1-12	N/A	C2	4
Ringenbach et al., 2015	Cycling	10	8-16	male (5), female (5)	C3	2
Caniz et al., 2018	Cycling	4	14-17	male (3), female (1)	C4	3
					Cycling Avg	3.1
Jimeno, 2019	NMT	6	9-16	female (2), male (4)	N1	2
Shavikloo et al., 2018	NMT	24	6-10	male (24)	N2	1
Cristian & Elsayed, 2019	NMT	7	7-10	N/A	N3	1
Lochbaum & Crews, 2003	NMT	5	16-21	N/A	N4	1
Kolzowski et al, 2020	NMT	58	7-12	N/A	N5	2
					NMT Avg	1.4
Koenig et al., 2012	Yoga	46	5-12	female (9), male (37)	Y1	3
Sotoodeh et al., 2017	Yoga	29	7-12	N/A	Y2	2
Narasingharao et al. 2018	yoga	68	5-16	N/A	Y3	2
Kaur & Bhat, 2019	yoga	24	5-13	N/A	Y4	2
radhakrishna et al., 2010	yoga	6	8-14	male (5), female (1)	Y5	2
					Yoga Avg	2.2
Hilton et al., 2014	exergaming	7	6-13	male (5), female (2)	G1	2
Caro et al., 2017	exergaming	7		N/A	G2	4
Anderson-Hanley et al., 2011	exergaming	22	3-22	N/A	EG1	3
Peña et al., 2020	exergaming	12	5-12	N/A	EG2	2
					gaming Avg	2.75
Cai et al., 2020	basketball	59	3-6	N/A	B1	1
Duffy et al., 2017	running	8	13-20	N/A	R1	4
Gabriels et al., 2015	Horseback riding	116	6-16	N/A	HR1	3
Bahrami et al., 2012	Martial Arts	30	5-16	male (26), female (4)	MA1	3
Bass et al., 2009	Horseback riding	19	5-10	male (17), female (2)	HR2	3
					Rec Sports Avg	2.8

mild	1
mild to moderate	2
moderate	3
moderate to severe	4

not being investigated. What's more, the National Autism Center (2015) has stated that an inclusive PA program can promote not only physical skills but also decrease negative behaviors (i.e., self-harm). Based on this knowledge, incorporating an inclusive environment to exercise interventions could increase the success of the outcomes. Furthermore, not only is the psychosocial environment important but also the physical environment. For example, Lee and Poretta (2012) specifically analyzed a pool environment and cited how beneficial it could be to develop motor skills in individuals with autism. They noted that buoyancy could allow individuals to practice better movement.

Lastly, only two studies (Pan, 2010; Sotoodeh, et al., 2017) directly reported if the participants were receiving other interventions (i.e., physical therapy, applied behavior analysis [ABA]). Pan provided the most detail, discussing how many participants received what specific kind of intervention: occupational therapy ($n = 6$), physical therapy ($n = 2$), group therapy ($n = 3$), and speech therapy ($n = 1$). Sotoodeh reported that participants were possibly receiving behavioral interventions and that they may also be on medication. Given that some studies recruited from institutions and schools specializing in persons with disabilities and/or ASD (Bahrami et al., 2012; Bass et al., 2009; Cristian

Table 9 Diagnostic criteria and tools provided

Author	Activity	Diagnostic tools and criteria
Yilmaz et al., 2004	Swimming	Recruited participants from Handicaps Search Institute of Anadolu University in Turkey
Pan, 2010	Swimming	"[…]diagnosed through medical and psychological assessment by experienced and knowledgeable physicians in the public hospitals"
Lawson & Little, 2017	Swimming	"Children with ASD (Autistic Disorder, Pervasive Developmental Disorder-Not Otherwise Specified, Asperger's Syndrome per DSM-IV or autism spectrum disorder per DSM-5 (American Psychiatric Association, 2003, 2013)"
Fragala-Pinkham et al., 2011	Swimming	"diagnosed with an ASD,[…] medically able to participate in an aquatic exercise programme, no anticipated medication or other intervention changes during the research study period, no requirement for constant individualized monitoring of medical or behavioural status and able to follow directions and comply with fitness testing"
Shams-Elden, 2017	Swimming	Autism diagnosis (per the DSM-V)
Ennis, 2011	Swimming	Autism diagnosis (per the DSM-V)
Hauck et al., 2014	Cycling	Autism diagnosis (per the DSM-V), BMI low enough that there were no safety risks (i.e., a research assistant could guide the participant on the bike and prevent falling)
Schmitz Olin et al., 2017	Cycling	"children with an Autism Diagnosis"
Ringenbach et al., 2015	Cycling	"[…]children with ASD under the age of 8 years were not recruited because they could not reach the pedals. Risk stratification included the Physical Activity Readiness Questionnaire (PAR-Q), and a physician's clearance for moderate intensity exercise was obtained if necessary. Any participants with a physical disability that would prevent them from completing the exercise interventions were not tested."
Castillo & Olive, 2018	Cycling	Participants had a diagnosis of down syndrome or autism spectrum condition, as well as social and motor handicaps
Jimeno, 2019	NMT	"At the center, a psychologist, occupational therapist or speech pathologist screened all participants for group suitability through observation and were available throughout the program to provide advice concerning individual participants."
Shavikloo & Norasteh, 2018	NMT	"In this research, Gilliam test was performed by a specialist psychiatrist and samples were selected based on the points obtained in the variables in a class […] Entry requirements were […] confirmation of autism disorder in the child."
Cristian & Elsayed, 2019	NMT	"The research community is composed of children with neurodevelopmental disorders in Hafez Center Academy for people with special needs. The sample of the research was chosen in a deliberate manner Children with neurodevelopmental disorders and the basic research sample Children after the exclusion of children with different disabilities and multiple disabilities."
Lochbaum & Crews, 2003	NMT	Autism diagnosis (per the DSM-V)
Kozlowski et al., 2020	NMT	The sample consisted of 58 children with ASD and without ID. These participants were recruited over two years from a summer psychosocial treatment program
Koenig et al., 2012	Yoga	Autism diagnosis (per the DSM-V), and located in large urban public schools (in NY) (convenience sample)
Sotoodeh, et al., 2017	Yoga	Children with ASD attending a school for autism in Tehran, Iran
Narasingharao, 2017	Yoga	"Children were previously diagnosed as autistic as per school records under the International Classification for Diseases, Tenth Edition"
Kaur & Bhat, 2019	Yoga	"Participants were recruited by distributing fliers in the local schools and through online postings on autism websites. The initial screening process included parents completing the Social Communication Questionnaire46 and/or providing a medical record confirming an ASD diagnosis for their child."
Radhakrishna et al., 2010	Yoga	Diagnosis of ASD via the ICD-10 criteria
Hilton et al., 2014	Gaming	ASD diagnosis (per the DSM-V)
Caro et al., 2017	Gaming	"children with ASD…"
Anderson-Hanley et al., 2011	Exergaming	Diagnosed with ASD, and some expressive language
Peña et al., 2020	Exergaming	Diagnosed with ASD, able to follow instruction, and not taking any medications
Cai et al., 2020	Basketball	Participants were recruited from Chuying Child Developmental Center and Starssailor Education Institution (all had ASD diagnoses)
Duffy et al., 2017	Running	ASD diagnosis coupled by severe learning disabilities

Table 9 (continued)

Author	Activity	Diagnostic tools and criteria
Gabriels et al., 2015	Horseback riding	"Participants were scheduled for an initial study diagnostic and NVIQ assessment visit at the first author's institution[…]," all participants had an ASD diagnosis, and were stratified via IQ (less or greater than 85)
Bahrami et al., 2012	Martial Arts	ASD diagnosis (per the DSM-5)
Bass et al., 2009	Horseback riding	Participants had an ASD diagnosis, and were recruited from the Agency of Persons with Disabilities (located in the University of Miami's Center for Autism Related Disabilities)

& Elsayed, 2019; Lochbaum & Crews, 2003; Schmitz Olin et al., 2017; Yilmaz et al., 2004), it is conceivable that more participants should have been reported having additional interventions considering the feasible resources that are likely to have been available (e.g., physical therapy, occupational therapy, ABA therapy). Clearly, given how additional outside interventions may affect the results of the studies at hand, future research should report these characteristics of the participants. Not only does this account for possible confounds in the analysis, but may also reveal a relationship between interventions that provide the most success when combined.

Commonalities of Interventions

A common finding for the swimming interventions was an increase in social skills. Research has found that the sensorimotor cortex region of the brain is hyperreactive in Participants with ASD (Chen et al., 2018). As a result, participants with ASD may become internally drawn to cope with the hyper-arousing external environment, and thus cause them to disengage with activities and others. Based on this knowledge, PA may be an especially important invention, as it provides a multisensory experience (externally and internally), as well as motor coordination training (Han et al., 2018; Heyn, 2003). This multisensory experience can aid in allowing participants with ASD to be more externally focused rather than internally. This could be why interventions such as swimming led to increases in social skills. Once more focused on their surrounding environments rather than themselves, the participants were better able to communicate with those around them. What is more, hydrotherapy has been shown to decrease the sensory overload seen via hydrostatic pressure provided (described as providing a soothing environment) (Mooventhan & Nivethitha, 2014). Additionally, swimming tied for the lowest number of sessions per week (see Table 1). This might be explained by the availability of the pool. These interventions most often occurred in a community-pool setting, which may have decreased the availability of the resources. Moreover, these interventions were led by experts and therapists, and this also may have limited the frequency of the intervention due to time constraints.

There were two common findings for the cycling intervention: aerobic endurance and strength. This is also found in the work of Fowler et al. (2007)who studied the effects of stationary cycling in participants ranging in age from 7 to 18 years of age. The results showed that gross motor function, endurance, and strength were all significantly increased. This suggests that cycling is an effective intervention for multiple populations and should be further utilized as an intervention for strength, endurance, and motor function. Finally, cycling had the highest average for sessions per week, but the lowest average in the length of weeks. While it is difficult to suggest a reason for this consistent finding amongst cycling interventions, it might be suggested that the high frequency of sessions could have decreased the need for more weeks. Future research may aim to study a longer duration of a cycling intervention and observe if positive outcomes are increased. What is more, observing if the number of sessions in total is more prominent in results, or the number of sessions per week could help further this intervention style.

A consistent finding in the neuromuscular studies was an increase in aerobic endurance, strength, and balance. These results can be explained by the work of Batrakoulis et al. (2018), who found that a neuromuscular training program significantly increased aerobic capacity in female participants. Batrakoulis also found that strength associated with musculoskeletal factors (i.e., ligaments, muscles, tendons) showed significant improvement. This aligns with the findings of this review in that neuromuscular training improved strength, aerobic endurance, and balance. Additionally, this study found that these effects were still significant ten months after the intervention. Another supporting article for neuromuscular training improving balance comes from the work of Paterno et al. (2004). This research focused on using neuromuscular training to improve static balance in participants 13 to 17 years old. The results showed that there was a significant improvement in single-limb total stability and posterior stability. What is more, the average of this intervention was 8 weeks. This might be explained by the standard training block (a block is typically a 4-week period where specific skills are focused on). The interventions ranged from 5 to 16 weeks, all accounting for at least one training block or more. Future research may focus on combining training elements of neuromuscular training (i.e., plyometrics and weightlifting), as this is a common practice in populations without disabilities. Exploring the outcomes of this sort of training in participants with ASD is important, as it has been proven useful in other populations (Perez-Gomez, et al., 2008).

A consistent result among the yoga interventions was an improvement in balance. These findings are also found in other populations, such as individuals with chronic stroke. For example, a study by Schmid et al. (2012) found that yoga was an effective intervention for balance. Specifically, the Schmid study found that a group environment was beneficial for improving multiple post-stroke variables (the balance being one and the other being a fear of falling). Moreover, a study analyzing the effects of yoga on inner-city children (Berger et al., 2009) found that the intervention significantly improved balance for the test group of children. Finally, the slow, methodical movements associated with yoga could have a calming effect on children with ASD and reduce the associated hyperactivity that is often seen in children with ASD. Further research is needed to examine if yoga does reduce hyperactivity in children with ASD. Finally, the yoga interventions had the highest duration of weeks. It is difficult to explain why, but one major reason could be that two of the interventions utilized a school setting (and lasted the length of a school year or semester) (Koenig et al., 2012; Narasingharao, 2017). While it was shown that physical benefits are seen after yoga, future research may explore more cognitive-focused outcomes. Yoga is a practice that takes patience and generally produces a calming-effects. Therefore, focusing more on the cognitive aspects of Participants with ASD could be beneficial to forming yoga interventions.

A consistent finding in the literature for sports as an intervention was the improvement of social skills. This might be explained by the work of Eime et al. (2013), who studied the social health outcomes of sports participation. Their work found that social isolation was decreased after participating in a team setting with sports and increased social interaction and participation later in life. Based on this research, it can be seen that sports are not only a physical health intervention, but also promotes social skills. Finally, sports as an intervention had the highest session duration. This might be explained by the longer duration needed for large group settings to acquire the necessary repetitions, such as is seen with sports teams. Future research may explore the influence of being involved in a sports team year-round with multiple outlets of sport (i.e., playing basketball in the fall season, baseball in the spring season, and horseback riding in the summer). It seems from the cited literature that sports, in general, are beneficial to participants with ASD, and therefore being involved in a diverse group of sports may be useful. More specific research is needed on this idea but exploring how multiple sports interventions affect outcomes also may be a beneficial approach.

A common dependent variable studied in exergaming was cognition. The few studies that did examine the effects of exergaming on participants with ASD did find an improvement in cognition as measured by memory (Anderson-Hanley et al., 2011), focus duration (Caro et al., 2017), and working memory (Hilton et al., 2014). Improvement in cognition is also found in other studies, such as the work of Staiano and Calvert (2011), which found that exergaming could develop spatial awareness, attention, and understanding of cause-and-effect relationships. This review also suggests that exergaming can teach participants to respond to visual feedback, plan actions, understand spatial constraints, and even create a cognitive map of their bodily movements. What is more, the research of Gao and Mandryk (2012) looked at how casual exergaming could benefit cognitive performance. This work found that casual exergaming produced higher scores on two cognitive tests that analyzed focus and concentration, and also in the affective states of the participants after playing the games. Another important aspect of the exergaming was how short the duration of the intervention was. This might be explained by the setting of the intervention, which was often in physical therapy. The equipment for the video games was also limited to only this setting, and therefore could only be completed as many times a week as therapy was being given. There were still benefits from the intervention, so it may be concluded that this intervention does not need high exposure to be successful. Future research may look at increasing this duration, to observe if outcomes continue in a linear pattern or plateau. Another route of research may be to explore the effects of more common videogames that may hold therapeutic benefits. Such as games on gaming consoles that are more commonly found in households, the genre of video games most beneficial, and possibly the ideal duration of this intervention daily.

While running was not explored as an intervention, a running intervention was seen in the sport intervention category (Duffy et al., 2017). One variable this intervention analyzed was cognition and found that there was an acute change in cognitive style (i.e., how individuals remember things). This might be explained by the research of Moon and van Praag (2018), who focused on neural plasticity and running. Importantly, this review cites how exercise has the potential to modify brain structures such as the hippocampus (an area vital for learning and memory). This change in structure through exercise could explain the trend of change in cognitive styles that were found were prior research (Duffy et al., 2017). The same review cites how running, in particular, could be potent for restructuring the hippocampus due to the increase in neurogenesis it has been shown to promote. The review goes so far as to express how running can result in a two to three-fold increase in new neurons. This neurogenesis would be critical for neural plasticity and changes in cognitive function. Therefore, running may be a critical intervention for cognitive deficits. Future research may create more diverse running interventions (i.e., adjusting intensity or duration) and analyze the cognitive outcomes for individuals on the autism spectrum. If running is as critical for neurological health as it is suggested by the literature, more research is needed to explore if all cardiovascular interventions hold this potential for participants with ASD, or if running is unique in this result.

Lastly, it is important to note that all of these interventions were instruction-based with guided coaching and teaching. This is an important aspect, as the research of Lee and Porretta (2016) demonstrated that instructional-based learning is significantly more effective in reducing extraneous behaviors in ASD than free-play interventions. These researchers analyzed a baseline of stereotypic behaviors during free-play and then used intervention of instruction (in swimming and gymnastics activities), which resulted in participants decreasing their stereotypical behavior during instruction. The authors also note that simply providing age-appropriate activities and equipment is not enough to guarantee natural participation, as instruction and a structured environment are vital for the success of an intervention.

Limitations

While the cited studies are empirical, there are some limitations to the analysis of this systematic review. Each study was specific about its intervention duration (weeks, times per week, and length of session each week); however, the reasoning behind these numbers was not discussed. Therefore, while many of the interventions within the same category had similar durations, it was not often explained by the researchers why this duration or session length was used. Therefore, the authors of this review are unable to further analyze the interventions seen, and the possible benefits or deficits in their setup. What is more, not all of the cited studies specified details about the participants, with only 34% of the studies revealing their gender. While this does not change the outcomes of the studies, it does reduce some transparency of results or trends in data if any are present. For example, exploring if females respond with greater strength increases for some reason or if males respond with higher cognitive testing after yoga. Continuing on this argument of gender, there was a significant lapse of female participants in the studies that did identify gender. While autism does affect males more often, females are still affected and need an adequate amount of inclusiveness in the research.

Conclusion

The purpose of this paper was to review the literature on PA as a treatment for symptoms associated with ASD and provide enough background that this research might be applied in real-world scenarios. The present review found that many forms of PA ranging from aquatics to yoga to exergaming had a positive effect on specific ASD symptoms. Examples of positive outcomes included social skills, communication, and cognitive functioning as well as other physical benefits such as improved fitness, improved motor skills, balance, and spatial awareness. PA as an intervention should continue to be provided to children and young adults with ASD, and empirical studies should analyze PA as a treatment and continue to explore the unique benefits of PA on ASD. Additionally, more work is needed on the exact dosage of PA as treatment including factors such as time per session, length of the program, and intensity of the PA. More systematic research is needed to answer questions such as, "Is 30 min of aquatics, yoga, or cycling once a week enough to demonstrate significant changes in targeted behaviors?" "Are longer sessions conducted multiple times per week needed?".

Moreover, none of the studies included a complete range of ASD diagnoses. Future research may look to modify these interventions so that they would be more accessible and inclusive for all ranges of ASD. For example, balancing interventions could be modified by providing an assisted balance option so that a participant with a severe ASD diagnosis could participate. Also, many of the studies did not allow participants with ASD and a known comorbid disability diagnosis to participate. While it is understood that this would add some confounding issues to the research due to behavioral or physical limitations, it can also be argued that these interventions are most needed in such cases. In general, expanding the interventions to more participants with ASD and learning to modify movements and skills would greatly increase the number of individuals that could benefit. While the discussed research is novel and seems hopeful in producing benefits, the current authors would argue that it is not inclusive enough and more replication of the given interventions is needed with more diversity of ASD (not limited to only severity, but also more comorbidities). A major reason behind this argument is that the research is not inclusive of the 95% of ASD diagnoses that have comorbidities (Soke, et al., 2018).

Declarations

Conflict of Interest The authors declare no competing interests.

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