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ORIGINAL PAPER

How Do Physical Activity and Sedentary Behaviour Affect Motor Competence in Children with Autism Spectrum Disorder Compared to Typically Developing Children: A Pilot Study

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Abstract

Older children with Autism Spectrum Disorder (ASD) have high levels of motor impairment, however we are unsure if similar patterns exist in young children. This study aimed to investigate motor competence in four-to-seven-year-old children with (n = 17) and without (n = 17) ASD. A series of ANOVAS indicated children with ASD performed significantly poorer on all measures of motor competence, except MABC-2 manual dexterity and ball skills subscales. Results indicate that moderate-to-vigorous physical activity (PA) and sedentary behaviour (SB) may influence motor competence, regardless of diagnosis. Establishing appropriate levels of engagement in moderate-to-vigorous PA and SB during early school years is important for the development of all children and may be an important early intervention avenue for motor impairment in children with ASD.

Keywords Autism Spectrum Disorder · Physical Activity · Sedentary Behaviour · Motor Competence · Motor Impairment · Accelerometry

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by deficits in social communication and interaction, along with restricted and repetitive patterns of behavior (DSM-5; American Psychiatric Association, 2013). ASD is estimated to affect 2–4% of the population (May et al., 2017) affecting a ratio of 3:1 male to female, with a typical age of diagnosis of three years (Baio et al., 2018). Motor impairment is a common feature of ASD, affecting approximately 21–79% of primary school aged children with an ASD diagnosis (Green et al., 2009; Liu & Breslin, 2013), compared to 5–6% of typically developing (TD) children (Zwicker et al., 2012). Whilst motor impairment is not officially a core feature of ASD in the DSM-5 (APA, 2013), systematic reviews of the literature suggest that the majority of children with ASD will have some form of motor impairment (Fournier et al., 2010; Lum, et al., 2020). Providing a holistic understanding of motor competence in young children with ASD will better inform early interventions to improve motor competence.

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Motor Competence and Appropriate Measurement in Young Children

To address motor impairment, it is important that children have opportunities for motor development. Motor competence is defined as the mastery of physical skills, including both gross (e.g. running) and fine (e.g. manual dexterity) motor skills as well as the underlying patterns of movement (e.g. coordination, control and quality of movement) that enable participation in physical activity (PA) (Robinson et al., 2015). Motor competence is typically used as an

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umbrella term for the various mechanisms that describe goal directed movement (Robinson et al., 2015), such as fundamental movement skills (FMS; the activation of large muscle groups classified as object control and locomotor skills), and motor proficiency (Robinson et al., 2015). The complexity of motor competence means that it cannot be captured through the simple measurement of a particular skill or even set of skills (i.e. fine or gross motor). The measurement of motor competence can be objective, subjective or a hybrid of both types of measurements, with each form having its own unique set of strengths and limitations (for detailed information, see Bardid et al., 2019; Barnett et al., 2020). Objective methods commonly used in motor skill evaluation are process and product assessments. Process-oriented tests measure the quality of the movement (e.g., observable criteria within a skill, such as the elongated stride before a soccer/football kick) (Bardid et al., 2019), for example the Test of Gross Motor Development (TGMD; Ulrich, 2000; Webster & Ulrich, 2017), whilst product-oriented assessments measure the outcome of the movement (i.e. number of catches) for example the Movement Assessment Battery for Children-2 (M-ABC 2, Henderson & Sugden, 1992).

Despite the benefits of using standard movement batteries, a proportion of children with ASD may not be able to complete them, due to low levels of motor competence, lack of motivation, ASD severity, and cognitive ability, leading to challenges in understanding and following instructions and the potential for inaccurate measurement outcomes (Green et al., 2009). Subjective measurement, such as parent report, may therefore be an efficient and feasible way to gain initial information regarding the motor competence of children with ASD. If a child is identified to have low motor competence, clinicians can implement objective movement assessments to highlight specific areas of difficulty and develop an appropriately targeted intervention.

Motor Impairment in ASD

Past research indicates that deficits in motor skill development (i.e. motor impairment) may be present before deficits in social interaction and communication, and deficits in motor skills may exacerbate deficits in social skills and communication skills, such as interacting socially (i.e. nodding head) (Leary & Hill, 1996). Motor skill impairments may be among the earliest measurable signs of ASD (Nayate et al., 2005; Gowen & Hamilton, 2013). Motor deficits including "odd gait, clumsiness, and other abnormal motor signs (e.g. walking on tiptoes)" are included as associated features of the disorder in the DSM-5 (pg. 55; APA, 2013) and are not considered to be core features of ASD. Deficits in praxis, motor planning, gait, coordination and postural control have been documented in individuals with ASD, along with delays in both gross and fine motor domains (Fournier et al., 2010; Jeste, 2011). Whilst previous research indicates that motor ability may improve as children age, either as a result of natural development or due to early intervention (Fournier et al., 2010), the variability in levels of motor ability in children with ASD is more pronounced than that of TD children at the same developmental stage (Lindor et al., 2019). Atypical gait and ocular motor dysfunction may be detectable on product (i.e. MABC-2) and process (i.e. TGMD-2) measures of fine and gross motor skills. Further to this, poorer motor function is associated with increased severity of ASD symptomology and emotional/behavioural disturbances (Papadopoulos et al., 2012).

Previous research has investigated motor impairment using the MABC-2 three to six-year age band (Craig et al., 2018; Kopp et al., 2010; Van Waelvelde, 2010), with results indicating children with ASD have or are at risk of developing motor impairment. However, it should be noted that the Craig et al (2018) study included children with ASD and Intellectual Disability (ID) in comparison to children with ID only, whilst those in the Van Waelvelde et al. (2010) study were at risk for ASD, Attention Deficit-Hyperactivity Disorder (ADHD) or Developmental Coordination Disorder (DCD).

Further research has combined children in the same age band as the current study (3–6 years) with the findings of children in older age bands (7–10 years, 11–14 years), also indicating that children with ASD perform poorer on measures of the MABC-2 when compared to TD children (Hanaie et al., 2016; Liu & Breslin, 2013; Manicolo et al., 2019). It should be noted that the mean age in these studies was between nine and 12 years, and the results for the children assessed under the 3–6-year age band were not separated from those assessed using the 7–10- or 11–14-year bands. Larger scale studies with older children have found that up to 79–82% of children with ASD had motor impairments when assessed using product assessments such as the MABC-2 (Bremer & Cairney, 2019; Green et al., 2009; Liu et al., 2019).

When considering process assessments (i.e. TGMD-2), few studies have explicitly examined motor skills in four to six-year-old children with ASD. Dadgar et al. (2017) allude to poor motor skills in their three to five-year-old participants with ASD (n = 20), however no explicit reports of TGMD-2 scores were provided. MacDonald et al. (2013) reported that the object control skill subscale of the TGMD-2 significantly predicted ASD severity in six to 15-year-old children with ASD. In addition, Liu et al. (2014) reported that children with ASD (n = 21, Mage = 7.57 years) performed significantly poorer on the locomotor, object control subscales and the total TGMD-2, compared to TD children (n = 21, Mage = 7.38 years). Implications of reduced motor competence may impact daily tasks (i.e. getting dressed), and reduce levels of PA which may have a flow on effect to increased levels of social isolation.

Physical Activity, Sedentary Behaviour and the Interaction With Motor Competence

Stodden et al. (2008) presented a reciprocal model between motor competence and physical activity, and the associated factors that enable or hinder this association throughout childhood and into adolescence. Further to this Stodden et al. suggested that engagement in PA drives motor competence in young children, and that higher levels of PA provide more opportunities to develop motor skills. The findings were echoed in a longitudinal study showing the reciprocal association lasts throughout childhood and into adolescence (Lima et al., 2017). The reciprocal relationship between motor competence and PA has also been established in research in older children (7–12 years) with movement difficulties, such as DCD or children with ID (Green et al., 2011; Westendorp et al., 2011) finding positive associations between higher levels of motor skills and participation.

A recent study of ecological correlates of moderate-to-vigorous PA reported that younger children, aged four to seven years, with ASD engaged in similar levels of PA as TD children, with both groups failing to meet the minimum World Health Organisation (2019) requirements of 60 min of moderate-to-vigorous PA per day (Thomas et al., 2019). However, adolescents with a diagnosis of ASD generally engage in less PA than their TD counterparts (McCoy et al., 2016). Children with ASD have fewer opportunities to participate in PA than their TD peers (Obrusnikova & Cavalier, 2011) and are 60% less likely to participate in regular PA (McCoy et al., 2016). However, this apparent reduction in PA as children with ASD age, may be due to the inability to fully develop FMS, which are considered to be the building blocks for more progressive movement and sport-specific skills (Gandotra et al., 2020).

Independent of physical activity, prolonged sedentary behavior (SB) adversely affects children's health. SB is associated with poorer physical, mental, social and academic profiles, regardless of diagnosis (Hinkley et al., 2014). Whilst older children with ASD engage in higher levels of SB than TD children (MacDonald et al., 2011; Tyler et al., 2014), younger children appear to engage in similar amounts of SB as TD children, with both groups engaging in five times the WHO (2016) recommend amounts of a maximum of 60 min of SB daily (Thomas et al., 2020). Associations between SB and motor skill have been noted in TD populations, with those engaging in higher levels of SB reported to have lower levels of objectively measured motor skills (Cliff et al., 2016; Graf et al., 2004). However, Ketcheson, et al. (2018) report significant differences in levels of SB in young children (two to five years) with ASD (n = 34), after controlling for fine, gross and total motor skill, compared to TD children (n = 19), indicating that motor skill may not be a contributing factor to engagement in SB (Ketcheson, et al., 2018). It is important to establish the interaction between PA, SB and motor skill in preschool and early primary school aged children as this is a critical period in motor skill development that sets the scene for future engagement in PA, as childhood PA tracks into adolescence and adulthood—making childhood an essential time to intervene and develop positive PA behaviours. The model by Stodden et al. (2008) has been applied in the ASD field with older children (Liu & Breslin, 2013) and adolescents (Jeoung, 2018; Pan, 2011), demonstrating that children with ASD engage in less PA, higher levels of SB and have poorer motor skills than TD children (Ketcheson, et al., 2018; Yang et al., 2015).

Limited studies have considered the impact that PA has on motor skills in children with ASD. The majority of motor skill studies in this population have focused on improving emotional and behavioural functioning, or the reduction of restrictive and repetitive behaviours, and subjective measurement only (e.g. Bass et al., 2009; Hameury et al., 2010). Two studies to date have used objective measures of motor skills and PA in children with ASD (Pan, 2010, 2011) (n = 16 and n = 15 respectively). Yet, no research has explicitly explored how motor competence, a well-established deficit in older children with ASD, might be associated with PA and SB in four to seven-year-old children with ASD. To date no research has investigated motor skill level in young children with ASD in comparison to TD children using multiple standardized objective and subjective tests of motor competence, which may further enhance the knowledge of the complex nature of motor competence. Understanding the developmental trajectory for young children with ASD may provide a clearer path for interventions to enhance motor competence as they develop, thus improving functional outcomes such as PA and social communication.

Aims

The aims of the current study were to (1) determine the level of motor competence in four to seven-year-old children with ASD compared to TD children using both objective and subjective measures; (2) determine if accelerometer measured moderate-to-vigorous-intensity PA and SB are associated with motor competence; (3) determine if the influence of moderate-to-vigorous-intensity PA or SB on motor competence differs for children with ASD compared to TD children. It was hypothesized that children with an ASD diagnosis will perform significantly poorer on all measures of motor competence, in comparison to TD children. It was also hypothesized that higher levels of moderate-to-vigorous-intensity PA would be associated with greater motor competence and that this association would be stronger for children with ASD compared to TD children. Finally, it was hypothesized that SB would be negatively associated with motor competence and that this association would be stronger for children with ASD compared to TD children.

Method

Participants

The current study is one of a series of studies investigating ecological correlates of PA and SB in young children with ASD. Children with a confirmed ASD diagnosis, aged four to seven years (n = 17) and a matched sample of TD children (n = 17) took part in the current study. Recruitment of participants from the larger study has been described in detail elsewhere (Thomas et al., 2019). Approval by Deakin Human Research Ethics Committee (2014-061) and the Department of Education and Training (2015_002795) was granted. Informed consent was obtained from parents of ASD and TD children in line with the Declaration of Helsinki. The reporting of this study corresponds to the STROBE statement (von Elm et al., 2007). Children with a confirmed diagnosis by a multidisciplinary team of DSM-IV Autistic Disorder or Asperger's Disorder or DSM-5 Autism Spectrum Disorder (ASD) were recruited from specialist Autism services and private paediatric clinics in Melbourne, Victoria. Inclusion criteria for those with ASD was an Social Responsiveness scale (SRS-2; Constantino & Gruber, 2012) score of over 59 (clinical range). Children were excluded if they had previously been diagnosed with a genetic condition (e.g., Fragile X Syndrome) or a neurological condition which impacted on their motor skills (e.g., Cerebral Palsy). TD children were a convenience sample from local preschools and primary schools and were excluded if they had an SRS-II score over 59. Children from the ASD and TD groups who did not have valid accelerometry data were excluded (n = 34).

Procedure

A letter of support from Autism service providers and paediatric clinics was sent to parents of children with ASD, along with the plain language statement inviting them to participate in the study. Interested families contacted the research team directly to attend an assessment session in a location of their choosing (their home, the university or their service provider). For the TD group, a letter of support from the school principal, along with the PLS was sent to all parents. Interested families contacted the school, who provided a final list of participants to the researchers.

Assessment of children's cognitive ability and motor skills were completed within two hours and included breaks if needed. During the child assessment session, parents of children with ASD completed the surveys according to their standard instructions. The surveys included demographic information for themselves, their partner (if applicable) and their child. The surveys also covered measures of individual, familial and physical environment domain variables and a proxy measure of child motor skill. Parents were provided instructions regarding their child wearing the Actigraph accelerometer for eight consecutive days after the completion of the assessment. Parents of TD children received the survey from their school and returned it along with the accelerometer to the school after the required time period. Parents of ASD children returned the survey and accelerometer to the research team via a prepaid satchel.

Measures

Demographics

Primary caregivers of participants in both the ASD and TD groups, reported their child's date of birth, and sex, their relationship to their child, their own age, sex, country of birth, employment status, highest education level and marital status. Caregivers of the children with ASD reported on the type of ASD diagnosis.

Motor Competence

Motor competence was assessed via the MABC-2 (Henderson et al., 2007). The MABC-2 is comprised of eight items which derive three component standard scores (manual dexterity, aiming and catching, and balancing) and provides levels of motor proficiency (no problems, at risk, definite motor problems). For the current study the three to six-year age band was utilized. Test–retest reliability has been reported to be between 0.86 and 0.91 for children as young as three years (Henderson et al., 2007). The MABC has been previously used in children with ASD (e.g. Green et al., 2009). We report on all three component standard scores and the total score, which is calculated by summing the three component scores. We also report on the zones of motor competence based on the child's overall motor competence score and age (Green (> 15th percentile) = no apparent movement difficulties; Amber (6th–15th percentile) = at risk or needs further investigation; Red (5th percentile) = definite movement difficulties).

Fundamental Movement Skills

Fundamental movement skills were assessed using the TGMD-2 (Ulrich, 2000) by trained examiners according to established procedure. The TGMD-2 has well-established internal consistency with Cronbach's alpha ≥ 0.85 for locomotor and object control subtests, test–retest and intra-rater reliability > 0.85 (Ulrich, 2000). The TGMD-2 has been previously used in children with ASD (MacDonald et al., 2013). A demonstration of each skill was given which was assessed twice to derive a trial one and trial two score. The performance of the children was scored live and also recorded for consistency. Each skill was evaluated by three to five performance criteria and a score of one was granted if a skill was performed correctly and a score of zero if not. Scores on both trials were added to derive a raw score for each skill that were summed to obtain a total raw score on locomotor (run, gallop, hop, leap, horizontal jump and slide) and object control subscales (striking a stationary ball, stationary dribble, catch, kick, overhand throw, and underhand roll). Scores on each sub-scale ranged from 0–48. The current study reports on both the locomotor and object control subscales, which were summed to obtain a total individual score. The total standard score was also used, which was calculated by converting the total individual score to a standard score based on the child's age and sex (Ulrich, 2000).

Parent Assessment of Their Child's Fundamental Movement Skill Competence

Parent assessment of their child's fundamental movement skill competence using an adapted version of the pictorial scale of the Perceived Movement Skill Competence (PMSC) (Barnett et al., 2015). The PMSC was designed so that each skill item was matched to the skills in the TGMD-2. The parent version was designed to assess the parents' perceptions of their child's FMS competence on 12 FMS (six locomotor and six object control skills) (Liong et al., 2015). The items and wording on the parent version are similar to the PMSC with a picture of each skill performed well. However, the parents rated 'how good' they thought their child was at the 12 skills on a 4-point Likert Scale. If the child had not tried a skill before, the parents were asked to indicate what they 'thought' their child would be like. The scores on run, gallop, hop, leap, jump and slide were added to form the locomotor competence score. Similarly scores on throw, catch, roll, kick, hop and bounce were summed to obtain an object control competence score. The FMS competence score was computed by adding the locomotor and object control competence scores. Thus, the score on each sub-scale ranged from six to 24, and a total FMS competence score ranged from 12–48. More recently, the parent version of the PMSC was used in a Spanish sample of parents where the scale showed high internal consistency (0.86, 95% CI 0.83–0.89). (Estevan et al., 2017).

Physical Activity Participation and Sedentary Behavior

Physical activity participation and sedentary behavior was evaluated using Actigraph accelerometers (model wGT3X+BT), which provide objective PA assessment of intensity and duration. Actigraph monitors are the most widely used objective method of assessing free-living, habitual activity in children (Trost et al., 2005) and have established validity, reliability and utility in early childhood (Cliff et al., 2009). Actigraph are small, lightweight devices, which were worn on a belt on the right iliac crest for eight consecutive days. Actigraph monitors have verified high validity against criterion measures including indirect calorimetry (Trost et al., 2005; 2011). Participants were required to remove the accelerometers when sleeping or whilst performing water-based activities. We report on average minutes per day in SB and moderate to vigorousPA, and base compliance levels with WHO (2016; 2019) recommendations for PA and SB.

Cognitive Ability

Cognitive ability was assessed using standardized instructions with either the Wechsler Preschool and Primary Scales of Intelligence IV (WPPSI-IV; Wechsler, 2012), or the Psychoeducational Profile 3 (PEP-3; Schopler et al., 2005). Those who were unable to complete the WPPSI-IV due to low cognitive ability were assessed using the PEP-3, which includes tasks suitable for young children with ASD who also experience intellectual delays and offers a cognitive developmental age up to seven years. The WPPSI-IV has sound psychometric properties, with a reliability coefficient of 0.96 for FSIQ and test–retest reliability ranging from 0.84 to 0.89 (Wechsler, 2012). Similarly, PEP-3 has sound internal consistency, test–retest reliability, and inter-rater reliability with correlations ranging from 0.78 to 0.99 (Schopler et al., 2005). A dichotomous variable was created for children with ASD (intellectual disability; yes/no) children with ASD with a score on the WPPSI-IV of ≤ 70, or the completion of the PEP-3 were considered to be intellectually disabled. The continuous FSIQ score of the WPPSI-IV was used for the TD sample.

Data Management and Statistical Analysis

All data were screened for data entry errors, cleaned and screened for missing data, and outliers. Normality was assessed via the use of graphs and statistical analysis. All analyses were conducted using IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp, 2016). Descriptive statistics were run to characterise the samples including sex, age, level of cognitive ability, via the use of t-test and chi-squared tests

Table 1 Sample characteristics of the ASD and TD cohorts

	ASD (n = 17)	TD (n = 17)	p
Child			
Age in months: M (SD)	66.19 (10.22)	68.47 (6.22)	0.45
Male: n (%)	13 (76.5%)	8 (47.1%)	0.12
Diagnosis (ASD group only)			
Autistic	4 (23.5%)		
ASD	7 (41.2%)		
PDD-NOS	5 (29.4%)		
Asperger's Disorder	1 (5.9%)		
Intellectual disability [yes(n%)]	1 (5.9%)	0 (0%)	0.33
Sedentary behaviour (min/day)	335.17 (95.57)	378.38 (129.90)	0.28
MVPA (min/day)	87.03 (38.28)	82.10 (40.45)	0.71
Meets MVPA guidelines [yes(n%)]	12 (70.6%)	11 (64.7%)	0.72
Participates in organized sport weekly [yes (n%)]	15 (88%)	15 (88%)	1.00
Parent			
Sex [female (n%)]	15 (88.2%)	15 (93.8%)	0.60
Age in years M (SD)	36.24 (4.90)	37.69 (3.51)	.34
Educational Qualifications			
Year 12/ Trade certificate/Apprenticeship	7 (41%)	2 (12.5%)	0.07
University Degree/ Post graduate	10 (59%)	15 (87.5%)	
Employment status [yes (n%)]	14 (93%)	5 (31%)	< 0.001
Marital status [married (n%)]	14 (82.4%)	25 (96%)	0.20
SEIFA score M (SD)	1051.59 (48.81)	1044.12 (38.15)	0.62
Place of birth [Australia (n%)]	15 (88.2%)	10 (62.5%)	0.09

ASD Autism Spectrum Disorder, *PDD-NOS* Pervasive Developmental Disorder Not Otherwise Specified, *MVPA* moderate-to-vigorous physical activity, *M* mean, *SD* standard deviation, *TD* typically developing, *SEIFA* Socioeconomic index for areas

for the ASD and TD groups, along with the overall sample. Additional descriptive statistics for the primary caregivers were provided including sex, age, level of education, employment status, and relationship status (Table 1). Levels of motor competence were examined using a series of t-tests to determine if the ASD and TD groups differed on objective and subjective measurement of motor competence. Aligning with established protocols for accelerometer use, counts were recorded in 15-s epochs to accurately capture the intermittent nature of children's PA (Colley et al., 2014). Individual participant data were extracted from raw data based on both the age of participant (in years) and the appropriate cut point for age and school status (attendance at preschool or primary school). Extracted data were reduced to total counts/day, minutes/day in intensity and average time in moderate-to-vigorous PA using age-appropriate cut-points. For children aged four-to-six years (not at school) (n = 12) the study utilized the moderate-to-vigorous PA cut points from the Pate et al. (2006) study, as validated by Janssen et al (2013) (≥ 420 counts.15 s-1). For children aged six and over attending school (n = 22), Freedson et al. (2005) cut points for moderate-to-vigorous PA were applied (≥ 743 counts.15 s-1). For SB, the study adopted the cut points as validated by Janssen et al (2013) (≤ 25 counts.15 s-1). A valid day was set at six hours of wear time, and a valid week comprised of any four days (Janz et al., 1995). Children whose data did not meet the valid week requirements were excluded. Effect sizes were calculated by standardizing to a mean of 0 and a standard deviation (SD) of 1. Effect sizes are considered as small i.e. ~ 0.20 SD, moderate i.e. ~ 0.50 SD and large i.e. ~ 0.80 SD (Cohen, 1992). The use of a moderate effect size is in line with previous research in this space (Ketcheson et al., 2018; Liu & Breslin, 2013; Swarnarajam & Christopher, 2019).

A series of 10 ANOVAs were run to ascertain if children who engaged in higher amounts of SB and lower amounts of moderate-to-vigorous PA, had lower levels of motor competence. Interactions between SB/moderate-to-vigorous PA, group (ASD, TD) and motor competence were achieved by centering continuous scores of SB and moderate-to-vigorous PA and creating a new variable (SB/moderate-to-vigorous physical activity x group).

Results

Demographics

No significant differences between the ASD and TD group were detected in child demographic measures (age, sex, intellectual disability, participation in organised sport). When considering the primary caregivers of the ASD and TD cohorts, only employment status statistically differed between caregivers, with 93% of parents in the TD group currently employed.

Levels of Motor Competence Experienced by Children With ASD and TD Children

Based on the MABC-2 total scores and subscales, descriptive data indicated all TD children were in the green zone (> 15th percentile), indicating that they had no movement difficulties or motor delays. In contrast, descriptive data showed that 70% of ASD children were in the green zone (> 15th percentile), while 18% were in the amber zone (6–15th percentile), demonstrating that they were at risk for motor delays, and the remaining 12% in the red zone (< 5th percentile; see Table 2). Results of a T-test revealed that ASD children had poorer performance on the MABC-2 total scale compared to TD children, however these results were only nearing significance ($p = 0.08$). In terms of the subscales, the ASD group performed significantly poorer in the MABC-2 balance and coordination subscale only, therefore was the only subscale used in further analysis. There was no significant difference in motor proficiency between groups for the manual dexterity or ball skills subscales of the MABC-2 (see Table 2). In terms of fundamental movement skills, children with ASD performed significantly poorer on the TGMD-2 total standard score compared to TD children (see Table 2). The ASD group performed significantly poorer in the locomotor standard subscale and object control standard subscale than the TD group (see Table 2). In addition, children with ASD were reported by the parents as having poorer FMS compared to TD children (see Table 2).

Table 2 Levels of motor competence experienced by children with ASD compared to TD children

	ASD M (SD)	TD M (SD)	p
MABC-2			
Total score	75.41 (14.93)	82.88 (8.31)	0.08
Balance & coordination subscale	25.88 (7.28)	32.94 (3.42)	< 0.001
Manual dexterity subscale	26.94 (8.76)	29.00 (6.78)	0.45
Ball Skills subscale	18.24 (5.64)	20.35 (3.90)	0.21
MABC-2 zones			
Green [n, (%)]	12 (70%)	17 (100%)	
Amber [n, (%)]	3 (18%)	0 (0%)	
Red [n, (%)]	2 (12%)	0 (0%)	
TGMD-2			
Total score	15.53 (3.83)	25.82 (4.59)	< 0.001
Locomotor subscale	7.35 (1.99)	12.12 (3.18)	< 0.001
Object control subscale	8.14 (2.63)	13.71 (2.34)	< 0.001
Parent report FMS	27.65 (5.99)	36.29 (9.32)	0.003
Locomotor subscale	13.64 (3.52)	18.29 (5.41)	0.01
Object control subscale	14.00 (4.11)	18.00 (4.76)	0.01

MABC-2 Movement assessment battery for children, *TGMD-2* Test of Gross Motor Development, *FMS* fundamental movement skills, *M* mean, *SD* standard deviation, *ASD* Autism Spectrum Disorder, *TD* typically developing

Prediction of Motor Competence by Moderate-to-vigorous Physical Activity and Group Membership

The interaction between moderate-to-vigorous physical activity and group was significant for the MABC balance and coordination subscale with the TD group higher (see Table 3). The interaction between moderate-to-vigorous PA and group for predicting individual differences in motor competence made a significant contribution. Of the three predictors, only group membership made a unique contribution, accounting for 28% percent of the variance in motor competence.

The interaction between moderate-to-vigorous PA and group predicted motor competence in terms of the TGMD-2 total test score, locomotor subscale, and object control subscale, with the TD group higher for all measurements of motor competence (see Table 4). Of the three predictors, only group membership made a unique contribution, accounting for 46%, 54%, and 59% percent of the variance in motor competence respectively.

The interaction between moderate-to-vigorous PA and group predicted perceptions of child FMS in terms of parent reported FMS, with the TD group higher (see Table 3). All three predictors made unique contributions, with the interaction between group membership and moderate-to-vigorous PA being the strongest predictor, accounting for 11% percent of the variance perceived levels of child FMS. The interaction between moderate-to-vigorous PA and group did not predict perceptions of child locomotor (n.s.) The interaction between moderate-to-vigorous PA and group predicted perceptions of child object control skills in terms of parent reported FMS, with the TD group higher (see Table 3). Of the three predictors only, the interaction between group membership and moderate-to-vigorous PA made a unique

Table 3 Prediction of motor competence using the MABC-2 balance and coordination subscale and parent reported FMS based moderate-to-vigorous physical activity and SB for children with and without ASD

	MABC-2 balance and coordination				Parent reported FMS			
	Model 1		Model 2		Model 1		Model 2	
Variables	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*
MVPA	−0.04	−0.29	0.06	0.11	−0.03	−0.16	−1.0*	−2.14
Group membership	0.54*	3.54	0.54*	3.49	0.52*	3.37	0.52*	3.56
MVPA × group membership			−0.11	−0.21			1.03*	2.20
Multiple R	0.54		0.54		0.52		0.61	
R^2	0.29		0.29		0.27		0.37	
Adjusted R^2	0.25		0.22		0.22		0.31	
ΔR^2	0.29		0.001		0.27		0.10	
F	6.40		4.15		5.75		5.92	
Δ F	6.40		0.05		5.75		4.34	
df	2, 31		1, 30		2, 31		1, 30	
Variables	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*
SB	0.04	−0.24	0.42	0.76	−0.14	−0.90	0.22	0.39
Group membership	0.55*	3.55	0.54*	3.47	0.55*	3.54	0.54*	3.46
SB × group membership			−0.48	−0.86			−0.37	−0.67
Multiple R	0.54		0.56		0.54		0.55	
R^2	0.29		0.31		0.29		0.30	
Adjusted R^2	0.25		0.02		0.24		0.23	
ΔR^2	0.29		0.02		0.29		0.01	
F	6.39		4.47		6.29		4.62	
Δ F	6.39		0.74		6.29		0.44	
df	2, 31		1, 30		2, 31		1, 30	

df Degrees of freedom, *$p < .05$, *SB* sedentary behaviour, *MVPA* moderate-to-vigorous physical activity, *MABC-2* Movement assessment battery for children, *M* mean, *SD* standard deviation, *FMS* fundamental movement skills, *ASD* Autism Spectrum Disorder, *TD* typically developing

contribution, accounting for 19% percent of the variance perceived levels of object control skills.

Prediction of Motor Competence by SB and Group Membership

The interaction between SB and group was significant for the MABC balance and coordination subscale with the TD group higher (see Table 3). Of the three predictors, only group membership made a unique contribution, accounting for 28% percent of the variance in motor competence.

The interaction between SB and group predicted motor competence in terms of the TGMD-2 total test score, locomotor subscale and object control subscale, with the TD group higher (see Table 4)**.** Of the three predictors, only group membership made a unique contribution, accounting for 58%, 44% and 55% percent of the variance in motor competence respectively.

The interaction between SB and group predicted motor competence in terms of parent reported FMS, with the TD group higher (see Table 4). Out of the three predictors, only group membership made a unique contribution, accounting for 27% percent of the variance in motor competence. The interaction between SB and group did not predict perceptions of child locomotor or object control (n.s.)

Discussion

It is now well established that in addition to social and communication impairment, many children with ASD also have motor proficiency deficits characterised by clumsiness, abnormal motor signs and odd gait (APA, 2013). However, we know little about motor competence, defined as the mastery of physical skills (fine and gross motor) and the underlying patterns of movement (e.g. coordination, control and quality of movement) that enable participation in not only PA, but daily life (Robinson et al., 2015). Only a handful of studies have investigated motor competence in young children with ASD in comparison to TD children using objective measures (either the TGMD-2 or MABC-2) and no studies have utilized both process and product-oriented assessments, alongside subjective assessment (parent report) in one study. Therefore, this study aimed to determine whether the level of motor competence in four to seven-year-old children

Table 4 Prediction of motor competence using the TGMD-2 total score and subscales, based on moderate-to-vigorous physical activity and SB for children with and without ASD

	TGMD-2 total test score				TGMD-2 locomotor subscale				TGMD-2 object control subscale			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
Variables	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*
MVPA	−0.14	−1.31	−0.35	−0.98	−0.04	−0.29	−0.06	−0.13	−0.23	−0.20	−0.62	−1.67
Group membership	0.77*	7.10	0.77*	7.01	0.68*	5.13	0.68*	5.04	0.74*	6.39	0.74*	6.39
MVPA × group membership			0.21	0.60			0.02	0.05			0.41	1.10
Multiple R	0.79		0.80		0.68		0.68		0.79		0.80	
R^2	0.63		0.64		0.46		0.46		0.63		0.64	
Adjusted R^2	0.61		0.60		0.43		0.41		0.60		0.60	
ΔR^2	0.63		0.004		0.46		<0.001		0.63		0.02	
F	26.68		17.54		13.34		8.61		22.53		16.12	
Δ F	26.68		0.36		13.34		0.002		22.53		1.20	
df	2, 31		1, 30		2, 31		1, 30		2, 31		1, 30	
Variables	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*	*Beta*	*t*
SB	−0.03	−0.30	0.31	0.75	−0.05	−0.39	0.39	0.81	−0.002	0.99	0.24	0.53
Group membership	0.79*	6.93	0.78*	6.84	0.69*	5.14	0.68*	5.01	0.76*	6.03	0.75*	5.29
SB × group membership			−0.36	−0.87			−0.46	−0.96			−0.25	−0.56
Multiple R	0.78		0.79		0.68		0.69		0.76		0.76	
R^2	0.61		0.62		0.46		0.48		0.57		0.58	
Adjusted R^2	0.59		0.58		0.43		-0.43		0.54		0.53	
ΔR^2	0.61		0.01		0.46		0.02		0.57		0.01	
F	24.58		16.51		13.40		9.27		18.77		12.31	
Δ F	24.58		0.76		13.40		0.93		18.77		0.31	
df	2, 31		1, 30		2, 31		1, 30		2, 31		1, 30	

df Degrees of freedom, *$p < .05$, *SB* sedentary behavior, moderate-to-vigorous physical activity, moderate-to-vigorous physical activity, *TGMD-2* Test of Gross Motor Development, *FMS* fundamental movement skills, *M* mean, *SD* standard deviation, *ASD* Autism Spectrum Disorder, *TD* typically developing

with ASD differed from TD children using objective and subjective measures of motor competence and to determine if moderate-to-vigorous PA and SB could predict motor competence.

The results of the current study found partial support for the first hypothesis that children aged between four and seven years with ASD would perform significantly poorer on all measures of motor competence (as measured by the MABC-2, TGMD-2 and parent report). The results indicated a significant difference between the ASD and TD groups on the MABC-2 subscale of balance and coordination. These findings are in line with past research reporting significant differences between children with and without ASD as measured by the MABC-2 subscales of balance and coordination (Hanaie et al., 2016). Past research using the MABC-2 has not focused on this subscale specifically, however the systematic review by Gandotra et al. (2020) note that children with higher severity of ASD had more issues with this subscale. Further to that, Gandotra et al. note that children with ASD+ID had higher levels of impairment than children with ASD or ID alone.

Similar performance between the ASD and TD groups in the current study on the MABC-2 subscales of manual dexterity and ball skills conflict with past research (Green et al., 2009; Liu & Breslin, 2013; Manicolo et al., 2019), potentially due to the younger age of children in the current study. Such findings may reflect the developmental period and the refinement of fine motor skills in all young children, regardless of diagnosis.

An interesting finding is that only 30% of ASD children in the current sample were in the amber (at risk of movement difficulties) or red zone (definite movement difficulties) of the MABC-2, which is lower than that of past research (i.e. Green et al., 2009; Liu & Breslin, 2013). Green et al. (2009) reported that 10% of their participants were in the amber zone and 79% in the red zone. Similar results were noted by Liu and Breslin (2013), who reported that 77% of their participants (Mage 7.96 years) fell into the red zone and an additional 3% were in the amber zone, however it is unclear where those who completed the 3–6-year age band assessment fell (n = 8). An explanation may relate to the cognitive ability of children in the current sample. Only one child in the ASD sample was intellectually delayed, which may account for the higher competency scores in the ASD group. However, research surrounding the impact of ID on motor competence is mixed, with some studies finding that children with ASD performed more poorly than children with ID alone (Craig et al., 2018; Paquet et al., 2016; Vanvuchelen et al., 2007) and others finding that children with ASD+ID performed more poorly than children with ASD alone (Papadopoulos et al., 2012; Paquet, et al., 2016; Vanvuchelen, et al., 2007).

Providing support to the first hypothesis, children in the ASD group performed significantly poorer on both of the subscales of the TGMD-2 and the total TGMD-2 scale than those in the TD group. Children in the ASD group performed significantly poorer than children in the TD group on all skills as measured by the parent proxy assessment of their FMS. Such findings lend support to past research regarding motor impairments in primary school aged children with ASD, finding significant differences between children with and without ASD on measurement on FMS (Dadgar et al., 2017; Liu et al, 2014; Swarnarajam & Christopher, 2019) which may account for reduced participation in PA in later childhood and adolescence (Gandotra, et al., 2020). The findings of objective measurement of FMS and parent reported FMS aligned for both the ASD and TD groups, indicating that parent reported assessments of FMS in young children may be a useful tool for initial motor assessments, or where the child is unable to complete a full motor assessment.

The second hypothesis that moderate-to-vigorous PA would be associated with motor competence and that this association would be stronger for children with ASD when compared to TD children, was partially supported, moderate-to-vigorous PA did not significantly predict a difference in MABC-2 or TGMD-2 total scores or subscales. However, moderate-to-vigorous PA was the strongest predictor of parent reported FMS, with children in the TD group performing better than those in the ASD group. This aligns with the model put forward by Stodden et al. (2008) who indicate that higher levels of PA may improve the development of motor competence in young children. Children in the ASD and TD groups both engaged in an average of 87 min of moderate-to-vigorous PA per day, which is greater than the WHO (2019) recommendations of 60 min per day for children aged over five. This high level of compliance with moderate-to-vigorous PA guidelines in both groups, may have had an impact on the remaining analyses as research has indicated that those who engage in higher levels of PA may have higher levels of motor competence (Bremer & Cairney, 2019). Such findings lend support to past studies regarding the positive impact that PA may have on motor skill development (Healy et al., 2018; Howells et al., 2019).

The third hypothesis, that higher levels of sedentary behaviour would be associated with lower motor competence and that this association would be stronger for children with ASD compared to TD children, was partially supported and reflects previous research (Bremer & Cairney, 2019; Cairney et al., 2006). Children in the TD group, regardless of level of SB, performed significantly better on the balance and coordination subscale of the MABC-2 than children with ASD, which supports past research in preschool aged children (Ketcheson et al., 2018).

The strengths of the current study include the broader view of motor competence, examining fine and gross motor, motor skill and coordination via the use of objective and subjective measurement of motor competence and objectively measured moderate-to-vigorous PA and SB in a matched Australian sample of children aged four to seven years. This approach provides a more in-depth examination of the complexity of motor proficiency with children with ASD. There was a good success rate of valid use of accelerometry with age appropriate cut points, which is discussed in more detail elsewhere (Thomas et al., 2019). It is important to note that all children, regardless of diagnosis, exceeded the recommended guidelines for SB by four hours a day (WHO, 2016, 2019), therefore results around the potential implication of SB on motor skill should be interpreted with caution. These findings are in line with past research (Ketcheson et al., 2018) who echo the high level of engagement in SB, regardless of diagnosis.

Limitations and Future Directions

Despite finding significant differences between the ASD and TD groups, the main limitation of the current study was the small sample size. However, past research examining motor competence and FMS in young children with ASD using similar measures, such as the MABC-2 (i.e. Ketcheson et al., 2018; Liu & Breslin, 2013; Pan, 2010, 2011) and TGMD-2 (i.e. Dadgar et al., 2017; Liu et al., 2014; Swarnarajam & Christopher, 2019) have done so with similar or smaller participant numbers and moderate effect sizes. It should also be noted that one participant in the ASD group had turned seven just prior to the assessment taking place, and was assessed using the 3–6-year age band of the MABC-2, and only one child had ID. Another limitation of the current study was related to the SES factors of participants. The study was conducted in Melbourne, Victoria, Australia. The SEIFA scored for both the ASD and TD groups indicate that neither group was disadvantaged. The majority of the parents of participants were also born in Australia, which limits the cultural diversity of the sample. The sample was also skewed in terms of gender matching, with a more even split of males/females in the TD sample. Whilst it has been established in TD literature that males are more physically active and have more developed motor skills than females, this has yet to be determined in young children with ASD (Jones et al., 2017). Nonetheless, the current study adds to the literature by further characterizing the differences in motor competence between young children with and without ASD across a range of measures. The significantly poorer performance in balance and coordination warrants further investigation. Balance and coordination are the underlying constructs of motor competence and may be a useful focal point for intervention. A recent pilot study by Howells et al. (2021) found a community football program improved total MABC-2, aiming and catching and balance scores, in 5–12 year old children with ASD. It is suggested that future research aims to repeat the methodology of the current study, with a larger, more culturally and socioeconomically diverse sample. It would also be useful to match participants not only on age, but also by gender and cognitive ability, and further examine the impact of differing levels of engagement in PA and SB during week and weekend days (Roscoe et al., 2019), which may further impact development of motor skills.

Conclusion

The current findings indicate high levels of moderate-to-vigorous PA in both the ASD and TD groups. The high compliance levels with PA guidelines may account for the lower rates of motor impairment in the ASD group compared to previous literature (i.e. Green et al., 2009; Liu & Breslin, 2013). These findings further reinforce the importance of established positive engagement in moderate-to-vigorous PA, which in turn develop locomotor skills, skill-related fitness and manipulative skills (Healy et al., 2018) and increases the likelihood of further engagement in sport as children age. Establishing appropriate levels of engagement in moderate-to-vigorous PA and SB during early school years is important for the development of all children and may be an important early intervention avenue for motor impairment in children with ASD.

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References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5)* (5th ed.). American Psychiatric Association.

Baio, J., Wiggins, L., Christensen, D. L., et al. (2018). Prevalance of autism spectrum disorder among children aged 8 years—autism and developmental disabilities monitoring network, 11 sites, United States, 2014. *Morbidity and Mortalilty Weekly Report, Surveillance Summaries, 67*(6), 1–23.

Bardid, F., Vannozzi, G., Logan, S. W., Hardy, L. L., & Barnett, L. M. (2019). A hitchhiker's guide to assessing young people's motor competence: Deciding what method to use. *Journal of Science and Medicine in Sport, 22*(3), 311–318.

Barnett, L. M., Ridgers, N. D., Zask, A., & Salmon, J. (2015). Face validity and reliability of a pictorial instrument for assessing fundamental movement skill percieved competence in young children. *Journal of Science and Medicine in Sport, 18*(10), 98–102.

Barnett, L. M., Stodden, D. F., Hulteen, R. M., & Sacko, R. S. (2020). Motor Competency Assessment. In T. A. Brusseau (Ed.), *The routledge handbook of pediatric physical activity* (pp. 384–408). Routledge.

Bass, M. M., Duchowny, C. A., & Llabre, M. M. (2009). The effect of therapeutic horseback riding on social functioning in children with autism. *Journal of Autism Spectrum Disorders, 39*(9), 1261–1267.

Cliff, D. P., Hesketh, K. D., Vella, S. A., Hinkley, T., Tsiros, M. D., Ridgers, N. D., Carver, A., Veitch, J., Parrish, A. M., Hardy, L. L., Plotnikoff, R. C., Okley, A. D., Salmon, J., & Lubans, D. R. (2016). Objectively measured sedentary behaviour and health and development in children and adolescents: Systematic review and meta-analysis. *Obesity Reviews, 17*(4), 330–344.

Cliff, D. P., Okely, A. D., Smith, L. M., & Kim, M. (2009). Relationships between fundamental movement skills and objectively measured physical activity in preschool children. *Paediatric Exercise Science, 21*(4), 436.

Colley, R. C., Harvey, A., Grattan, K. P., & Adamo, K. B. (2014). Impact of accelerometer epoch length on physical activity and sedentary behavior outcomes for preschool-aged children. *Health Report, 25*(1), 3–9.

Constantino, J. N., & Gruber, C. P. (2012). *Social responsiveness scale: SRS-2*. Torrance, CA: Western Psychological Services.

Craig, F., Lorenzo, A., Lucarelli, E., Russo, L., Fanizza, I., & Trabacca, A. (2018). Motor competency and social communication skills in preschool children with autism spectrum disorder. *Autism Research, 11*(6), 893–902.

Dadgar, H., Rad, J. A., Soleymani, Z., Khorammi, A., McCleery, J., & Maroufizadeh, S. (2017). The relationship between motor, imitation, and early social communication skills in children with autism. *Iranian Journal of Psychiatry, 12*(4), 236–240.

Estevan, I., Molina-Garcia, J., Bowe, S. J., Alvarez, O., Castillo, I., & Barnett, L. M. (2017). Who can best report on children's motor competence: Parents, teachers or the children themselves? *Psychology of Sport and Exercise, 34*, 1–9.

Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor Coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of Autism Development Disorders, 40*, 1227–1240.

Freedson, P., Pober, D., & Janz, K. F. (2005). Calibration of accelerometer output for children. *Medicine and Science in Sports and Exercise, 37*(11), S523–S530.

Gandotra, A., Kotyuk, E., Szkely, A., Kasos, K., Csirmaz, L., & Cserjsi, R. (2020). Fundamental movement skills in children with autism spectrum disorder: A systematic review. *Research in Autism Spectrum Disorders, 78*, 101632.

Graf, C., Koch, B., Dordel, S., Schindler-Marlow, S., Icks, A., Schuller, A., Bjarnason-Wehrens, B., Tokarski, W., & Predel, H. (2004). Physical activity, leisure habits and obesity in first-grade children. *European Journal of Cardiovascular Prevention and Rehabilitation, 11*, 284–290.

Green, D., Charman, T., Pickles, A., Chandler, S., Loucas, T., Simonoff, E., et al. (2009). Impairment in movement skills of children with autistic spectrum disorders. *Developmental Medicine and Child Neurology, 51*(4), 311–316.

Hameury, L., Delavous, P., Teste, B., Leroy, C., Gaboriau, J.-C., & Berthier, A. (2010). Equine-assisted therapy and autism. *Annales Medico-Psychologiques, Revue Psychiatrique, 168*(9), 655–659.

Hanaie, R., Mohri, I., Kagitani-Shimono, K., Tachibana, M., Matsuzaki, J., Hirata, I., Nagatani, F., Watanabe, Y., Fujita, N., & Taniike, M. (2016). White matter volume in the brainstem and inferior parietal lobule is related to motor performance in children with autism spectrum disorder: A voxel-based morphometry study. *Autism Research, 9*, 981–992.

Healy, S., Nacario, A., Braithwaite, R. E., & Hopper, C. (2018). The effect of physical activity interventions on youth with autism spectrum disorder: A meta-analysis. *Autism Research, 11*, 818–833.

Henderson, S., & Sugden, D. (1992). *The movement assessment battery for children*. The Psychological Corporation.

Henderson, S., Sugden, D., & Barnett, A. (2007). *The movement assessment battery for children*. The Psychological Corporation.

Hinkley, T., Teychenne, M., Downing, K. L., Ball, K., Salmon, J., & Hesketh, K. D. (2014). Early childhood physical activity, sedentary behaviors and psychosocial well-being: A systematic review. *Preventive Medicine, 62*, 182–192.

Howells, K., Sivaratnam, C., May, T., Lindor, E., McGillivray, J., & Rinehart, N. (2019). Efficacy of group-based organised physical activity participation for social outcomes in children with autism spectrum disorder: A systematic review and meta-analysis. *Journal of Autism and Developmental Disorders, 49*(8), 3290–3308.

Janssen, X., Cliff, D. P., Reilly, J. J., Hinkley, T., Jones, R. A., Batterham, M., Ekelund, U., Brage, S., & Okely, A. D. (2013). Predictive validity and classification accuracy of actigraph energy expenditure equations and cut-points in young children. *PLoS ONE, 8*(11), 1–9.

Janz, K. F., Whitt, J., & Mahoney, L. T. (1995). The stability of children's physical activity as measured by accelerometry and self-report. *Medicine & Science in Sports & Exercise, 27*(9), 1326–1332.

Jeste, S. S. (2011). The neurology of autism spectrum disorders. *Current Opinion in Neurology, 24*, 132–139.

Ketcheson, L., Huach, J. L., & Ulrich, D. (2018). The levels of physical activity and motor skills in young children with and without autism spectrum disorder, aged 2–5 years. *Autism, 22*(4), 414–423.

Kopp, S., Beckung, E., & Gillberg, C. (2010). Developmental coordination disorder and other motor control problems in girls with autism spectrum disorder and/or attention-deficit/hyperactivity disorder. *Research in Developmental Disabilities, 31*(2), 350–361.

Leary, M. R., & Hill, D. A. (1996). Moving on: Autism and movement disturbance. *Mental Retardation, 34*(1), 39–53.

Lima, R. A., Pfeiffer, K., Larsen, L. R., Bugge, A., Moller, N. C., Anderson, L. B., & Stodden, D. F. (2017). Physical activity and motor competence present a positive reciprocal longitudinal relationship across childhood and early adolescence. *Journal of Physical Activity and Health, 14*(6), 440–447.

Lindor, E. R., van Boxtel, J. J. A., Rinehart, N. J., & Fielding, J. (2019). Motor difficulties are associated with impaired perception of interactive human movement in autism spectrum disorder: A pilot study. *Journal of Clinical and Experimental Neuropsychology, 41*(8), 856–874.

Liong, G. H., Ridgers, N. D., & Barnett, L. M. (2015). Associations between skill perceptions and young children's actual fundamental movement skills. *Perception Motor Skills, 120*(2), 591–603.

Liu, T., & Breslin, C. M. (2013). Fine and gross motor performance of the MABC-2 by children with autism spectrum disorder and typically developing children. *Research in Autism Spectrum Disorders, 7*(10), 1244–1249.

Liu, T., Hamilton, M. L., Davis, L., & Elgarhy, S. (2014). Gross motor performance by children with autism spectrum disorder and typically developing children on TGMD-2. *Child and Adolescent Behaviour, 2*(1), 12.

Lum, J. G., Shandley, K., Albein-Urios, N., Kirkovski, M., Papadopoulos, N., Wilson, R. B., Enticott, P. G., & Rinehart, N. J. (2020). Meta-analysis reveals gait anomalies in autism. *Autism Research*. https://doi.org/10.1002/aur.2443

MacDonald, M., Esposito, P., & Ulrich, D. (2011). The physical activity patterns of children with autism. *BMC Research Notes, 4*, 422.

MacDonald, M., Lord, C., & Ulrich, D. A. (2013). The Relationship Of Motor Skills And Social Communicative Skills In School-Aged Children With Autism Spectrum Disorder. *Adapted Physical Activity Quarterly, 30*, 271–282.

Manicolo, O., Broztmann, M., Hagmann-von Arx, P., Grobb, A., & Weber, P. (2019). Gait in children with infantile/atypical autism: Age-dependent decrease in gait variability and associations with motor skills. *European Journal of Paediatric Neurology, 23*(1), 117–125.

May, T., Sciberras, E., Brignell, A., & Williams, K. (2017). Autism spectrum disorder: Updated prevalence and comparison of two birth cohorts in a nationally representative Australian sample. *British Medical Journal Open, 7*(5), e15549.

McCoy, S. M., Jakicic, J. M., & Gibbs, B. B. (2016). comparison of obesity, physical activity, and sedentary behaviors between adolescents with autism spectrum disorders and without. *Journal of Autism and Developmental Disorders, 46*(7), 2317–2326.

Obrusnikova, I., & Cavalier, A. R. (2011). Perceived barriers and facilitators of participation in after-school physical activity by children with autism spectrum disorders. *Journal of Developmental and Physical Disabilities, 23*(3), 195–211.

Pan, C. Y. (2010). Effect of water exercise swimming program on aquatic skills and social behaviors in children with autism spectrum disorders. *Autism, 14*(1), 9–28.

Pan, C. Y. (2011). Physical activity correlates for children with autism spectrum disorder in middle school physical education. *Research Quarterly for Exercise and Sport, 82*(3), 491–498.

Papadopoulos, N., McGinley, J., Tonge, B., Bradshaw, J., Saunders, K., Murphy, A., & Rinehart, N. (2012). Motor proficiency and emotional/behavioral disturbance in autism and Asperger's disorder: Another piece of the neurological puzzle? *Autism, 16*(6), 627–640.

Paquet, A., Olliac, B., Bouvard, M. P., Golse, B., & Vaivre-Douret, L. (2016). The semiology of motor disorders in autism spectrum disorders as highlighted from a standardized neuro-psychomotor assessment. *Frontiers in Psychology, 7*, 1292.

Pate, R. R., Almeida, M. J., McIver, K. L., Pfeiffer, K. A., & Dowda, M. (2006). Validation and calibration of physical activity monitors in preschool children. *Obesity, 14*(11), 2000–2006.

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., Rodrigues, L. P., & D'Hondt, E. (2015). Motor competence and its effect on positive developmental trajectories of health. *Sports Medicine, 45*(9), 1273–1284.

Roscoe, C. M., James, R. S., & Duncan, M. J. (2019). Accelerometer-based physical activity levels differ between week and weekend days in British preschool children. *Journal of Functional Morphology and Kinesiology, 4*(3), 65.

Schopler, E., Lansing, M., Reichler, R., & Marcus, L. (2005). *Examiner's manual of Psychoeducational Profile*. Pro-ed Incorporation.

Stodden, D. F., Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest, 60*(2), 290–306.

Swarnarajam, A., & Christopher, S. (2019). Gross motor skills in children with autism spectrum disorder and attention deficit hyperactive disorder. *Indian Journal of Public Health Research & Development, 10*(10), 1–6.

Thomas, S., Hinkley, T., Barnett, L. M., May, T., & Rinehart, N. (2019). Young children with ASD participate in the same level of physical activity as children without ASD: Implications for early intervention to maintain good health. *Journal of Autism and Developmental Disorders, 49*(8), 3278–3289.

Thomas, S., May, T., Barnett, L. M., Papadopoulos, N., McGillivray, J., & Rinehart, N. (2020). Ecological correlates of sedentary behavior in young children with autism spectrum disorder. *Research in Autism Spectrum Disorders, 78*, 101636.

Trost, S. G., McIver, K. L., & Pate, R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise, 37*(11 suppl), S531–S543.

Tyler, K., MacDonald, M., & Menear, K. (2014). Physical activity and physical fitness of school-aged children and youth with autism spectrum disorders. *Autism Research and Treatment*. https://doi.org/10.1155/2014/312163

Ulrich, D. A. (2000). *Test of gross motor development* (2nd ed.). University Press PRO-ED.

Van Waelvelde, H., Oostra, A., Dewitte, G., Van den Broeck, C., & Jongmans, M. J. (2010). Stability of motor problems in young children with or at risk of autism spectrum disorders, ADHD, and or developmental coordination disorder. *Developmental Medicine & Child Neurology, 52*(8), e174–e178.

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gotzsche, P. C., & Vandenbroucke, J. P. (2007). Strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guidelines for reporting observational studies. *PLOS Medicine, 4*, e296.

Wechsler, D. (2012). *Wechsler preschool and primary scales of intelligence* (4th ed.). Pearson.

World Health Organization. (2019) *Guidelines on physical activity, sedentary behaviour and sleep for children under 5 years of age*. World Health Organization.

Yang, Y. J., Siao, M. R., Tsai, F. T., & Luo, H. J. (2015). Effect of physical activity interventions on children and adolescents with autism spectrum disorder: A systematic review and meta-analysis. *Physiotherapy, 101*, e1685–e1686.

Zwicker, J. G., Missiuna, C., Harris, S. R., & Boyd, L. A. (2012). Developmental coordination disorder: A review and update. *European Journal of Paediatric Neurology, 16*(6), 573–581.

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