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Motor skills, visual perception, and visual-motor integration in children and youth with Autism Spectrum Disorder

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A R T I C L E I N F O

Keywords:
Autism Spectrum Disorder
Motor skills
Visual perception
Visual-motor integration

A B S T R A C T

Background: Motor skill deficits are prevalent among children with Autism Spectrum Disorder (ASD) however, little is known about the underlying mechanism of these deficits. In response to this gap, this study investigated how visual perception (VP) and visual-motor integration (VMI) are associated with motor skills among children and youth with ASD.
Methods: Sixty-seven individuals with ASD and sixty-seven age- and gender-matched individuals without ASD (age range: 9.83–15.13 years) participated. Motor skills were assessed with the Movement Assessment Battery for Children-2 (MABC-2) and VP and VMI with the respective components of the Beery-Buktenica Developmental Test of Visual-Motor Integration-6 (Beery VMI-6).
Results: Significantly more children and youth with ASD were in the red and orange zone of the MABC-2 traffic-lighting system for the total MABC-2 and the Aiming and Catching and Balance components compared to the children and youth without ASD. Both groups did not differ on the VP and VMI components of the Beery VMI-6. Pearson correlations between VP and VMI, and motor skills were weak but significant for the individuals without ASD, but not for the ASD group.
Conclusion: The current study added to the evidence about motor skill deficits among children and youth with ASD. VP and VMI were not related to motor skills, suggesting that these functions – as measured in the current study – are no underlying mechanisms of motor skill deficits of children with ASD and average intelligence. Diagnostic implications are provided for the evidence of motor skill deficits among children and youth with ASD.

1. Introduction

Autism Spectrum Disorder (ASD) is a pervasive neuro-developmental disorder, characterized by persistent deficits in communication, social interaction and restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association [APA], 2013; World Health Organisation [WHO], 2019). Characteristics of ASD are present in the early stages of childhood and can

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persist into adolescence and adulthood (APA, 2013; Pender, Fearon, Heron, & Mandy, 2020). The WHO (2019) estimated that worldwide 0.63 % of the children has ASD. In the Netherlands, 3.9 % of the children aged 4–12 years old were diagnosed with ASD in 2019 according to a health survey from the Statistics Office Netherlands (CBS, 2020; Netherlands Youth Institute, 2018). ASD co-occurs in approximately 28–44 % of the cases with Attention Deficit Hyperactivity Disorder (ADHD) (Lai, Lombardo, & Baron-Cohen, 2014; Leitner, 2014) and in approximately 15 % of the cases with Developmental Coordination Disorder (DCD) (Miller et al., 2021; Zampella, Wang, Haley, Hutchinson, & de Marchena, 2021). Although not included in the diagnostic criteria (APA, 2013), motor skill deficits are prevalent in individuals with ASD and were already present in the early descriptions of ASD by Kanner (1943). Also, studies have suggested that the earliest manifestation of ASD is atypical motor development being reflected as delay in achieving motor milestones (Chukoskie, Townsend, & Westerfield, 2013; Coll, Foster, Meilleur, Brambati, & Hyde, 2020; Downey & Rapport, 2012; West, 2019).

Numerous recent reviews and meta-analyses have shed a light on the broad range of motor challenges in ASD (Zampella et al., 2021). These include gait (Lum et al., 2021), maintaining and adjusting balance and posture while depending on visual information (Lim, Partridge, Girdler, & Morris, 2017; Stins & Emck, 2018), manual dexterity (Khoury et al., 2020), praxis, and problems in dynamical object manipulation such as aiming and catching (Zampella et al., 2021). The findings of the reviews include problems in basic motor ability and planning, generalized slowness and motor clumsiness (Khoury et al., 2020; Lim et al., 2017; Lum et al., 2021; Stins & Emck, 2018; Zampella et al., 2021). Although a few studies have argued that motor development of individuals with ASD is only delayed in childhood (Ming, Brimacombe, & Wagner, 2007; Paquet, Olliac, Golse, & Vaivre-Douret, 2016), the majority of studies suggests that motor problems persist into adolescence and adulthood (Chukoskie et al., 2013; Glazebrook, Elliott, & Szatmari, 2008; Nazarali, Glazebrook, & Elliott, 2009; Perry, Minassian, Lopez, Maron, & Lincoln, 2007; Travers, Powell, Klinger, & Klinger, 2013; Weiss, Moran, Parker, & Foley, 2013).

Several hypotheses have been suggested to explain the motor problems in individuals with ASD. The first hypothesis focusses on neurological functioning of the cerebellar and basal ganglia circuits (Allen, Müller, & Courchesne, 2004; Khoury et al., 2020; Mostofsky et al., 2009; Qiu, Adler, Crocetti, Miller, & Mostofsky, 2010). Neurological malfunctioning of these areas is commonly reported among individuals with ASD (Allen et al., 2004; Khoury et al., 2020; Mostofsky et al., 2009; Qiu et al., 2010), affecting their muscle tone including hypotonia, motor coordination, and automating motor behavior. Hypotonia is indeed often present in individuals with ASD (Gabis et al., 2021). The muscle weakness due to hypotonia, including 'floppiness' and hypermobility, could also to some extent explain the reported motor skill problems in individuals with ASD (Gabis et al., 2021; Lopez-Espejo, Nuñez, Moscoso, & Escobar, 2021). Furthermore, it is hypothesized that the central nervous system of individuals with ASD is hampered in efficiently selecting sensory information and integrate this information correctly into motor planning and execution (Khoury et al., 2020). This results in difficulty in tasks that require retroactive feedback corrections, perception and action coupling strategies, and in tasks that require coordinated movements between arms and legs (Gandotra et al., 2020; Khoury et al., 2020; Lidstone & Mostofsky, 2021). In line with the abovementioned, Lidstone and Mostofsky (2021) have hypothesized that some children with ASD are hampered in their ability to use visual information efficiently to build up internal representations of themselves and their surroundings. This may hamper predictive motor control.

As stated by Lidstone and Mostofsky (2021), some individuals with ASD are challenged in effective use of visual perception, i.e., the brain's ability to receive, interpret, and act upon visual stimuli (Schriber Orloff, 2004). Visual perception consists of several elements, of which strengths as well as weaknesses have been reported in individuals with ASD. Visual discrimination, the ability to distinguish one shape from another (Schriber Orloff, 2004), has been described as a strength of children with ASD as they tend to focus on details rather than the global image (Nayar, Voyles, Kiorpes, & Di Martino, 2017; Robertson & Baron-Cohen, 2017). However, recognition, discrimination and imitation of faces is frequently impaired (Boucher & Lewis, 1992; Klin et al., 1999; McAuliffe et al., 2020). This suggest that although visual perception of static stimuli is enhanced, visual perception of social and dynamic stimuli may be impaired (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Koh, Milne, & Dobkins, 2010; Robertson & Baron-Cohen, 2017; Spencer et al., 2000). Difficulties with imitation of others – in particular their motor movements – could therefore also explain some of the motor problems of children and youth with ASD as children usually learn motor skills via imitation. Visuo-spatial perception is the ability to move around in an environment, to orient appropriately, and to accurately reach for objects (Magill & Anderson, 2016; Mitchell & Ropar, 2004; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Muth, Hönekopp, & Falter, 2014). Children and youth with ASD are often described to be superior in static visuo-spatial perception (Bertone, Mottron, Jelenic, & Faubert, 2005; Muth et al., 2014) and inferior in dynamic visuo-spatial perception compared to typical developing (TD) controls (Bertone et al., 2005; Cardillo, Lanfranchi, & Mammarella, 2020; Van der Hallen, Manning, Evers, & Wagemans, 2019).

Visual-motor integration (VMI), the ability to guide movements by means of visual sensory information (Shin, Crapse, Mayo, & Sommer, 2009), has also been suggested as an underlying mechanism due to the problems with selecting and integrating sensory information for motor planning and execution, leading to motor problems among individuals with ASD (Gandotra et al., 2020; Khoury et al., 2020; Lidstone & Mostofsky, 2021). VMI is generally measured as the ability to copy geometric forms, for which the Beery Visual-Motor Integration (Beery VMI) test is mainly used (Beery & Beery, 2016). Children with ASD generally perform worse on the Beery VMI test (Green et al., 2016; Miller, Chukoskie, Townsend, & Trauner, 2014; Rosenblum, Amit Ben-Simhon, Meyer, & Gal, 2019) and other copying tests (Englund, Decker, Allen, & Roberts, 2014) than TD children. Also, when measured with a computerized touch screen task (Dowd, McGinley, Taffe, & Rinehart, 2012) children with ASD have difficulties with VMI. Thus, children with ASD seem challenged in coordinating eye-hand movements which may contribute to their motor skill deficits (Dowd et al., 2012; Englund et al., 2014; Green et al., 2016; Liu, 2013). Taken together, research findings so far seem to suggest that static VP is not related to motor performance in individuals with ASD and that VMI seems to affect motor performance in individuals with ASD. However, the associations between VMI, VP and motor skills in children with ASD has yet to be investigated. Investigating these associations may contribute to recognition of and intervention for the motor skills problems in this population.

Therefore, the first aim of this study was to examine motor skills, visual perception, and VMI of children and youth (ages 9–15) with ASD in comparison to age- and gender-matched individuals without ASD. The second aim was to determine if there is an association between motor skills, visual perception, and VMI among children and youth with and without ASD. Based on the previous research on static (Bertone et al., 2005; Muth et al., 2014) and dynamic visual perception (Bertone et al., 2005; Cardillo et al., 2020; Van der Hallen et al., 2019) we hypothesize that children and youth with ASD will perform better in visual perception as measured with the Beery VMI-6 (Beery & Beery, 2016) than children and youth without ASD. Additionally we hypothesize that children and youth with ASD perform worse in visual-motor integration (measured with the Beery VMI-6) and motor skills (measured with the MABC-2) than children and youth without ASD. Finally, we hypothesize that there are positive associations between visual perception, VMI, and motor skills among children and youth without ASD but not in children and youth with ASD. We expect the strongest, positive association between VMI and manual dexterity, as the VMI task used in the current study is a copying task and therefore requires good manual dexterity performance.

2. Methods

This study was part of the ‘Handwriting Study’, a collaborative research project taking place in the Netherlands and conducted between January 2019 and November 2020 by the Department of Occupational Therapy from the University of Haifa (Israel) and the Center of Human Movement Sciences and the Inclusive and Special Needs Education Unit from the University of Groningen (the Netherlands). The Handwriting Study was approved by the Ethics Committee of the Faculty of Social Welfare and Health Sciences,

Table 1
Demographic characteristics and diagnostic information of participants.

	ASD group		Non-ASD group		*t* (df)	*p*
	n or range	% or M (SD)	n or range	% or M (SD)		
Age in years	9.83–15.13	13.03 (1.12)	10.51–14.80	12.85 (1.11)	0.899 (132)	0.370
Gender						
Boys	54	80.6	54	80.6		
Girls	13	19.4	13	19.4		
Intelligence	78–122	100.59 (11.06)	75–119	99.56 (10.16)	0.558 (131)	0.578
Hand dominance						
Right hand	52	77.6	56	83.6		
Left hand	15	22.4	11	16.4		
ASD diagnosis[a]						
ASD	25	37.3				
Autism	7	10.4				
Asperger’s	7	10.4				
PDD-NOS	28	41.8				
Comorbid diagnoses[b]						
ADHD	18	26.9	7	10.4		
ADD			1	1.5		
DCD	2	3.0				
Dyslexia	1	1.5	1	1.5		
Attachment disorder	1	1.5				
Gilles de la Tourette	1	1.5				
MABC-2 Standard score	64		67			
– Green zone		24.6		50.7		
– Orange zone		21.5		26.9		
– Red zone		53.8		22.4		
MABC-2 Manual Dexterity	66		67			
– Green zone		14.9		22.4		
– Orange zone		28.4		28.4 %		
– Red zone		56.7		49.3 %		
MABC-2 Aiming Catching	66		67			
– Green zone		43.3		77.6		
– Orange zone		19.4		13.4		
– Red zone		37.3		9.0		
MABC-2 Balance	64		67			
– Green zone		63.1		76.1		
– Orange zone		21.5		20.9		
– Red zone		15.4		3.0		

Note. PDD-NOS pervasive developmental disorder not otherwise specified, *ADHD* attention deficit hyperactivity disorder, *ADD* attention deficit disorder, *DCD* developmental coordination disorder.

[a] As reported by parents in response to the question: ‘With which diagnosis in the autistic spectrum is your child diagnosed?’.

[b] As reported by parents in response to the question: ‘Apart from the diagnosis in the autistic spectrum, is your child diagnosed with another diagnoses? If yes, which?’ (ASD sample), or: ‘Is your child diagnosed with a learning or behavioral disorder?’ (Non-ASD sample).

University of Haifa (Israel) and the Ethics Committee of Pedagogical and Educational Sciences, University of Groningen (the Netherlands) and included measure of intelligence, executive functions, motor skills, visual perception, visual-motor integration, written content and handwriting process and product characteristics. One article has been published on the Handwriting Study, focusing on the relationship between written content and handwriting process and product characteristics (van den Bos, Houwen, Schoemaker, & Rosenblum, 2021). The current study solely focuses on the interrelationships between the measures motor skills, visual perception and visual-motor integration. After ethical approval, schools were approached for participation. Participating schools sent out invitations and an information letter about the study to parents. Participants could only participate if both parents provided active informed consent.

2.1. Participants

Participants were 67 Dutch children and youth with ASD (54 males, 80.6 %) and 67 Dutch children and youth without ASD (54 males, 80.6 %), matched for gender, age (M ± SD = 13.03 ± 1.12 years old, and M ± SD = 12.85 ± 1.11 years old respectively), and intelligence. Inclusion criteria for all participants of the 'Handwriting Study' were a) children and youth of grade 4 (ages 9, 10) to grade 9 (ages 14, 15) and b) children and youth who attend regular Dutch primary or secondary schools. In the Netherlands, only children with a level of intelligence in the normal range attend regular primary or secondary school. An additional inclusion criterion for participants with ASD was a prior diagnosis of ASD by a qualified professional according to the DSM-V (APA, 2013) or a diagnosis with autism, Asperger's or PDD-NOS according to the DSM-IV (APA, 2000) or ICD-10 (WHO, 2011). Medication history has not been taken into account in the study. See Table 1 for descriptive characteristics of participants and diagnostic information.

2.2. Instruments

2.2.1. Dutch Intelligence Test for Educational Level

The Dutch Intelligence Test for Educational Level (Nederlandse Intelligentietest voor Onderwijsniveau [NIO]; (Van Dijk & Tellegen, 2004)) was used to match participants for intelligence across groups. The NIO assesses global verbal and non-verbal intelligence and provides an indication of the appropriate school level of a child. In the current study, the verbal subscales 'analogies (25 items)' and 'categories (30 items)' were used, as well as the non-verbal subscales 'numbers (25 items)' and 'results (8 items)'. All items were multiple choice questions, with 1 point attributed to every good answer. A total intelligence score was computed as average of the four subscales, with a higher score indicating better performance and a population mean of 100 and standard deviation of 15. The test-retest reliability as well as the internal consistency of the NIO are good ($r = 0.88$, $r = 0.95$ respectively)(Van Dijk & Tellegen, 2004). The NIO correlated significantly with the CITO (Centraal Instituut voor Toetsontwikkeling) ($r = 0.78$), indicating high construct validity (Van Dijk & Tellegen, 2004).

2.2.2. Movement Assessment Battery for Children-2 (MABC-2)

The MABC-2 includes eight motor items grouped under the following three components: Manual Dexterity, Aiming and Catching, and Balance (Henderson, Sugden, & Barnett, 2007; Smits-Engelsman, 2010). The current study used age band two (7–10 years) and age band three (11–16 years). The raw scores of each item were converted into age-corrected standard scores per test item (item standard score) which together defined the total component standard score. The total test score is the sum of the component standard scores. The standard scores are interpreted with the MABC-2 traffic-light system, which categorizes scores in the red zone (i.e., standard score ≤ 5, indicating significant motor difficulties), orange zone (standard score between > 5 and ≤ 7, indicating risk of motor difficulties) and green zone (standard score >7, indicating no motor difficulties).

The interrater reliability (k = 0.94) was excellent for the total standard test score (Smits-Engelsman, Fiers, Henderson, & Henderson, 2008). The internal consistency of the MABC-2 components was good ($\alpha_{\text{Manual Dexterity}} = 0.81$, $\alpha_{\text{Aiming and Catching}} = 0.84$, $\alpha_{\text{Balance}} = 0.88$) (Wuang, Su, & Su, 2012). The MABC-2 correlated significantly with the Bruininks-Oseretsky Test of Motor Proficiency-Short Form ($r = 0.79$), indicating high construct validity (Jelsma, Niemeijer, & Smits-Engelsman, 2010).

2.2.3. Beery-Buktenica Developmental Test of Visual-Motor Integration, 6th Edition (BEERY VMI-6)

The Beery VMI-6 is a screening tool for identifying difficulties in visual-motor integration (Beery & Beery, 2016). The Beery VMI-6 consists of 24 geometric figures which the participant is required to copy on paper with a pencil. The copied geometric forms are scored with objective scoring criteria outlined in the test manual which define the extent to which the copied form resembles the original form. Possible scores range from 1 to 27 with a higher score indicating a better result. Raw scores can be transformed into norm scores corrected for age. The test-retest reliability of the Beery VMI-6 (ICC = 0.88) and the internal reliability (range: ICC = 0.75–0.88) were excellent (Beery, Buktenica, & Beery, 2011; Harvey et al., 2017). The concurrent validity of the Beery VMI-6 with the Copying subtest of the Developmental Test of Visual Perception – 2nd edition (Hammill, Pearson, Voress, & Frostig, 1993) and the Wide Range Assessment of Visual-Motor Abilities (Adams, Sheslow, & Wide Range, 1995) are both moderate (ICC = 0.75, ICC=0.52 respectively) (Beery & Beery, 2016; Beery et al., 2011; Beery, 2006).

2.2.4. Beery VMI developmental test of Visual Perception (VP)

The VP is a component of the Beery VMI-6. Children are shown 27 geometrical figures and for each figure that is shown, they are presented with three to seven alternatives from which they must choose the correct one. The aim is to identify as many correct figures in three minutes. Possible raw scores range from 1 to 27 with a higher score indicating a better result (Beery & Beery, 2016; Beery et al., 2011; Beery, 2006). Raw scores can be transformed into age-corrected norm scores. The test-retest reliability as well as the internal consistency of the VP test are good (ICC = 0.85, ICC = 0.84) (Beery & Beery, 2016; Beery et al., 2011; Beery, 2006). The construct validity between the VP test and the DTVP-2 Position-in-Space subtest as well as between the VP test and the DTVP-2 Eye-Coordination subtest has been found to be moderate (ICC = 0.62, and ICC = 0.65 respectively) (Beery, 2006; Beery et al., 2011; Beery & Beery, 2016).

2.3. Procedure

Children and youth with ASD were recruited from units for students with special educational needs of two primary and five secondary schools in the Netherlands. School management approached parents for participation of their child(ren) in the 'Handwriting study' if schools had records available of an official diagnosis in the autism spectrum provided by a certified psychologist. Children and youth without ASD were recruited from one primary and two secondary main stream schools in the Netherlands. If children matched the ASD sample for gender, age and intelligence, school management approached parents for participation of their child(ren) in the 'Handwriting study'.

The data was collected at the school of the participants during two meetings. In the first group meeting, participants were briefed regarding the purpose of the research and their rights to withdraw from participation at any time, after which the measure for intelligence (NIO) was administered in a group setting. In the second meeting, participants were assessed individually with the remaining tests (MABC-2, Beery-VMI, Beery-VP) in a quiet room. Data were collected by research assistants, who first received training in administration of the tests. In addition, the Beery VMI-6 was coded by research assistants. The VMI of each participant was coded by two independent coders. Interrater reliability between the coders was excellent (ICC = 0.941). The mean score between both assessors was used in the analyzes. The VMI test and the VP test were always tested together either before or after the MABC-2 in randomized order.

2.4. Data analysis

Statistical analyses were performed with IBM SPSS Statistics 26. The level of significance was set at < 0.05. An a priori G*Power analysis (Faul, Erdfelder, Lang, & Buchner, 2007) was performed to determine the sample size needed for the t-tests and correlation. With a power of .80, a medium effect size, and an error probability of .05, 128 participants are required for the t-test, and 94 participants for the correlation. The present sample of 134 subjects was therefore sufficient for both analyzes.

To examine possible differences in performance on motor skills, VP and VMI for children and youth with ASD as compared to children and youth without ASD, independent t-tests were performed on the standardizes scores of the Beery VMI-6 and VP component, the standard scores of the MABC-2 components (Manual Dexterity, Aiming and Catching, and Balance) and the total MABC-2. Assumptions were checked and met. Cohen's d was used to determine the effect size, with $d > 0.20$ indicating a small effect size, $d > 0.50$ indicating a medium effect size, and $d > 0.80$ indicating a large effect size.

Bivariate Pearson correlations were used to assess the association between norm scores of the Beery VMI-6 and the standard total scores of the MABC-2, as well as between the norm scores of the VP test and the standard scores of the MABC-2 for both groups. Pearson correlations were also calculated between the VP, and VMI norm scores and standard component scores of the MABC-2. Assumptions were checked and met.

3. Results

3.1. Descriptive statistics

Descriptive statistics for the VP test, VMI test, and MABC-2 for children and youth with and without ASD are summarized in Table 2. Distribution of the MABC-2 scores according to the traffic-light scoring system in children and youth with and without ASD are presented in Table 1. When inspecting the distribution within each zone, 75 % of the children and youth with ASD and 49.3 % of the children and youth without ASD are in the red or orange zone for the MABC-2 total score. No significant differences were found

Table 2
Descriptive statistics and differences in VMI test, VP test, MABC-2, Manual dexterity, Aiming and Catching and Balance component scores between children and youth with (n = 67) and without ASD (n = 67).

Variables	ASD group (mean ± SD)	Non-ASD group (mean ± SD)	t^a (df)	p (two-tailed)	d^b
VMI norm score	81.11 ± 13.89	78.87 ± 13.48	0.95 (131)	0.345	0.164
VP norm score	97.93 ± 9.00	99.82 ± 8.47	-1.26 (132)	0.212	0.216
Standard score MABC-2	5.88 ± 2.86	7.61 ± 2.39	-3.79 (130)	< 0.001***	0.660
MABC-2 MD	5.31 ± 2.43	6.15 ± 2.57	-1.93 (132)	0.055	0.334
MABC-2 AC	7.30 ± 3.66	9.40 ± 2.81	-3.74 (120.86)	0.001***	0.646
MABC-2 B	8.20 ± 2.85	9.66 ± 2.21	-3.29 (130)	0.001**	0.572

Note. VMI = Visual-Motor Integration; VP = Visual Perception; MABC-2 = Movement Assessment Battery for Children-2nd edition; MD = Manual Dexterity; AC = Aiming and Catching; B = Balance. [a] Independent t-test; [b]Cohen's D.
* p < .05. ** p < .01. *** p < .001.

between children and youth with and without ASD for the VMI test, VP test and Manual Dexterity scores. Children and youth with ASD scored significantly poorer on the total MABC-2 and the Aiming and Catching and Balance components as compared to children and youth without ASD with effect sizes indicating medium effects.

3.2. Pearson correlations

Table 3 presents the Pearson correlations between VP, VMI and motor skills. Non-significant very weak to weak Pearson correlations were found between the VP test, the VMI test, and the MABC-2 in the ASD group (ranges $r = -0.002$ to .223). However, significant, but weak correlations were found between the VMI test and the total MABC-2 ($r = 0.260$, $p = .034$) and the VMI test and the MABC-2 Manual Dexterity component ($r = 0.284$, $p = .020$) in the group non-ASD group, indicating that among children and youth without ASD better visual-motor integration is related to better total as well as fine motor skills (see Table 3). Fig. 1 presents the correlations between the VMI and Manual Dexterity scores in the ASD group and the group without ASD.

4. Discussion

4.1. Main findings

The first aim of the current study was to examine the VP, VMI and motor skills of 9- to 15-year-old children and youth with ASD as compared to age- and gender-matched peers without ASD. Differences between children and youth with and without ASD were found for overall motor skills (total MABC-2) as well as for the Aiming and Catching and Balance components of the MABC-2. No significant differences were found for VP, VMI, and the Manual Dexterity component of the MABC-2. Furthermore, 75 % of the children and youth with ASD (compared to 49.3 % in the non-ASD group) scored in the orange and red zone for the total MABC-2, which indicates risk of or significant motor difficulties. When looking more specifically to the separate components, significantly more children and youth with ASD compared to children and youth without ASD were in the red and orange zone for Aiming and Catching and Balance components but not for Manual Dexterity component.

The large percentages of children and youth with ASD in the red and orange zone for the total MABC-2 are similar to other studies among children and youth with ASD (Bhat, 2020; Green et al., 2009; Liu, 2013). In the study of Green et al. (2009) among 10–14-year-old children with ASD, it was found that 79 % of children scored in the red zone and another 10 % scored in the orange zone of the MABC. The study of Liu (2013) studied a younger group of children with ASD (ages 5–7-year-old) and also showed that 78 % of the children with ASD scored in the red zone and an additional 6 % scored in the orange zone. The findings of the current study thus support earlier research suggesting that children and youth with ASD are challenged with respect to their overall motor performance (Green et al., 2009; Liu, 2013). Therefore, motor skill deficits should be taken in consideration in the diagnostic process, as it often is an underrecognized problem. Additionally, future research should investigate the onset of motor skill deficits and the consequences of such severe motor skill deficits to further develop specific motor interventions.

The large percentages of children and youth with ASD within the orange and red zone of the total MABC-2 could largely be retraced to the Manual Dexterity component for which 85.1 % of the children and youth with ASD scored in these zones. Similar findings were found for the group of children and youth without ASD, with high percentages in the red and orange zone for the Manual Dexterity component (77.7 %) and hence, the total score. The large percentage of boys in our sample (80.6 %), in line with a general over-representation of males among individuals with ASD (Loomes, Hull, & Mandy, 2017), may explain the poor Manual Dexterity scores in both groups. Although no separate norm scores exist for boys and girls in the MABC-2 manual, differences between sexes have been found in which girls perform better on the total MABC-2 test as well as the Manual Dexterity component in various age groups (Fairbairn et al., 2020; Kokštejn, Musálek, & Tufano, 2017; Valtr, Psotta, & Abdollahipour, 2016).

Table 3
Correlations between VP, VMI and motor skills (MABC-2, manual dexterity, aiming/catching and balance) scores.

	ASD group r (P)	Non-ASD group r (P)
VP - VMI	0.223 (0.072)	0.151 (0.223)
VP - MABC-2	0.005 (0.971)	0.161 (0.194)
VP - Manual dexterity	0.028 (0.822)	0.200 (0.105)
VP - Aiming and Catching	0.109 (0.381)	-0.011 (0.930)
VP - Balance	-0.139 (0.271)	0.152 (0.220)
VMI - MABC-2	0.097 (0.446)	0.319 (0.009*)
VMI - Manual dexterity	0.105 (0.402)	0.264 (0.031*)
VMI - Aiming and Catching	0.129 (0.301)	0.084 (0.501)
VMI - Balance	-0.002 (0.989)	0.185 (0.135)

Note. VMI = Visual-Motor Integration; VP = Visual Perception; MABC-2 = Movement Assessment Battery for Children-2.
Pearson correlation; < 0.5 indicates low correlation; 0.5–0.7 indicates moderate correlation; > 0.7 indicates high correlation.
* Indicates significant correlation at $p < .05$.

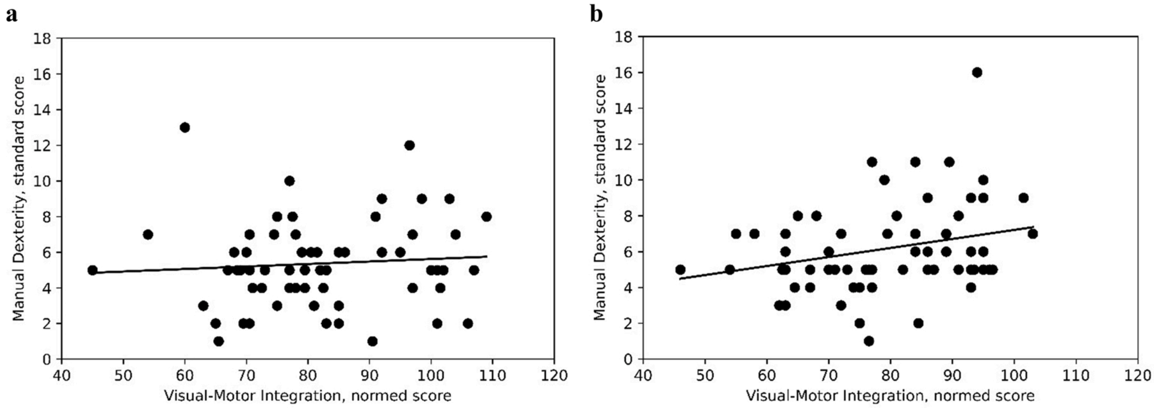

Fig. 1. Distribution of correlation between Manual Dexterity and Visual-Motor Integration scores. (a) Distribution of children and youth with ASD. (b) Distribution of children and youth without ASD.

In the current study, no significant differences were found between children and youth with and without ASD for VP or VMI as measured with the Beery VMI-6. Static VP, tested in the current study, has been reported as one of the strengths of children with ASD as they tend to focus on details rather than the global image (visual discrimination) (Robertson & Baron-Cohen, 2017). It is possible that the VP measured with the Beery VMI-6 does not explore the full potential of visual discrimination in the children and youth with ASD, resulting in similar results to the children and youth without ASD, as well as the population mean. It is possible that differences may manifest itself more in other, more difficult static visual stimuli, or in dynamic visual stimuli rather than the static visual stimuli tested in this study. Future research should focus on both static and dynamic visual stimuli to replicate these findings.

Finally, the VMI test is a copying task and therefore could be seen as a manual dexterity task. The poor scores of children and youth without ASD on the Manual Dexterity component of the MABC-2 could explain why no significant differences were found for the VMI test between both groups. Future research should explore VMI differences between children with ASD and a control group with manual dexterity scores within the normal range to provide a definitive conclusion.

The second aim of this study was to explore associations between VP, VMI and motor skills among children and youth with and without ASD. No significant correlations were found in either the ASD or without ASD group between VP and VMI, or between VP and motor skills. Several studies have suggested that VP and VMI are different – potentially unrelated – constructs (Bonifacci, 2004; Colarusso & Hammill, 2003; Fang, Wang, Zhang, & Qin, 2017; Henderson, Barnett, & Henderson, 1994; Leonard, Foxcroft, & Kroukamp, 1988; Schoemaker et al., 2001). In contrast, other studies suggest that VP and VMI are related constructs (Brown, 2012; Sigmundsson & Hopkins, 2005), similar to the authors of the Beery VMI-6 test Beery and Beery (2016) who mentioned a significant correlation of $r = 0.48$ between both constructs, and suggesting they are moderately related. However, the correlation suggests that although they are related, there is substantial unexplained variance suggesting these constructs are related though not similar. More research is needed to define (inter)dependence of both constructs.

Previous research had suggested that children with ASD are challenged in using VP for imitation and in dynamic situations to guide their motor behavior (Bertone et al., 2005; Boucher & Lewis, 1992; Cardillo et al., 2020; Klin et al., 1999; Van der Hallen et al., 2019). In particular, visuo-spatial perception, is suggested to be related to motor performance (Magill & Anderson, 2016; Mitchell & Ropar, 2004; Mottron et al., 2006; Muth et al., 2014). Based upon this research we expected to find a significant association between VP and motor performance in children and youth without ASD but not in children and youth with ASD. A possible explanation for not finding any association between VP and motor skills may be due to the type of VP measurement used in the present study. The Beery VMI-6 VP test measures form consistency which is a static form of VP. Future research should investigate how different types of VP – static VP, dynamic VP and visuo-spatial perception, as well as VP measured with different measurement instruments, each relate to motor skills in children and youth with and without ASD.

Finally, we expected to find significant correlations between VMI and motor skills, as Lidstone and Mostofsky (2021) argue that individuals with ASD are challenged in their ability to integrate visual information in the planning of motor skills. Associations were mainly expected for the Manual Dexterity component, as the VMI test is a copying task and therefore requires good manual dexterity performance. Although VMI was related to manual dexterity among children and youth without ASD, no significant correlations were found among children and youth with ASD. This may suggest that both concepts relate differently to each other across groups. Future research should investigate in more detail how these domains relate to each other across groups and to what potentially other motor and/or sensory processes they may relate.

4.2. Strengths and limitations

This study was the first in its kind to investigate the relationship between VP, VMI, and motor skills among children and youth with ASD in comparison to children and youth without ASD. The results, based on a large sample, showed how motor skill deficits are common among children and youth with ASD, and reflected on the relationship between VP and VMI, and motor skills.

However, the current study had several limitations. First, the current study investigated one isolated measure of VP, which may explain a lack of significant correlations with the other constructs. Future research should focus on other measures of VP as well. Second, although the current study had a relative large sample of girls with ASD ($n = 13$) compared to most studies (Gandotra et al., 2020; Green et al., 2009, 2016), an even larger group of girls is needed in order to be able to examine if sex influences the current study's results, and what differences are present between boys and girls in terms of VP, VMI, and motor skills. Lastly, this study was part of the 'Handwriting Study' which aimed to assess factors associated with the handwriting of children and youth with and without ASD (van den Bos et al., 2021). The aim of the 'Handwriting Study' could explain the overrepresentation of low Manual Dexterity and VMI scores in the group without ASD. Parents may have been more likely to sign up children for this study if they were worried about their handwriting.

5. Conclusion

Findings of the current study show that children and youth with ASD perform similar to children and youth without ASD for VP and VMI (as measured with the Beery-VMI-6). However, atypical motor skill performance was found, suggesting that motor skill deficits should be taken in consideration in the diagnostic process, and in creating interventions for children and youth with ASD. VP and VMI, as measured in the current study, appeared not to relate to motor skill of children and youth with ASD. Additional research is necessary to examine the link between other measures of VP, VMI, and motor skill performance.

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CRediT authorship contribution statement

Leila Faber: Conceptualization, Formal analysis, Investigation, Writing – original draft, Visualization. **Nellie van den Bos:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Suzanne Houwen:** Resources, Writing – review & editing. **Marina M. Schoemaker:** Resources, Writing – review & editing, Supervision. **Sara Rosenblum:** Conceptualization, Methodology, Software, Writing – review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Conflict of interest

The authors have no conflicts of interest to declare.

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