Motor Deficits in Children with Autism Spectrum Disorder: A cross-syndrome study

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Lay Abstract

It is now generally accepted that children and adults with autism spectrum disorder (ASD) are at risk of having some level of motor difficulty. There is still an ongoing debate with regard to what particular areas of motor functioning are most affected, and how this may be related to specific areas of brain functioning. Communication difficulties are also a defining feature of ASD, and it is known that children with specific language impairment (SLI) are at risk of motor difficulties as well. The present study examined the similarities between the motor difficulties experienced by children with ASD and children with SLI using a range of fine and gross motor tests. The results showed that the motor skills of the children with ASD, and SLI, were significantly lower than typically developing controls, but that both groups of children had very similar levels of motor skills across all of the motor tests, with one exception. The children with ASD found a fine motor task, which involved threading a lace using both hands at the same time, particularly difficult. The findings of the present study show that children with ASD have significant motor difficulties which are largely similar in expression to those of children with SLI. It is important that future studies of motor skills in children with ASD include an SLI control group so that the specific neurological basis of motor control in children with ASD is more accurately identified.

Scientific Abstract

Recent research suggests that children with autism spectrum disorder (ASD) experience some level of motor difficulty, and that this may be associated with social communication skills. However, other studies show that children with language impairments, but without the social communication problems, are at risk of motor

difficulties as well. The aim of the present study was to determine if children with ASD have syndrome specific motor deficits in comparison to children with specific language impairment (SLI). We used an independent groups design with three groups of children (8-10 years old) matched on age and nonverbal IQ; an ASD group, an SLI group, and a typically developing (TD) group. All of the children completed an individually administered, standardized motor assessment battery. We found that the TD group demonstrated significantly better motor skills than either the ASD or SLI groups. Detailed analyses of the motor subtests revealed that the ASD and SLI groups had very similar motor profiles across a range of fine and gross motor skills, with one exception. We conclude that children with ASD, and SLI, are at risk of clinically significant motor deficits. However, future behavioural and neurological studies of motor skills in children with ASD should include an SLI comparison group in order to identify possible autism specific deficits.

Keywords: Autism spectrum disorder; specific language impairment; motor deficit.

Introduction

Autism spectrum disorder (ASD) is defined, in DSM-5, as a neurodevelopmental disorder characterised by 'persistent deficits in social communication and social interaction across multiple contexts' [American Psychiatric Association, 2013, p.50]. While 'stereotyped or repetitive motor movements' are described as possible manifestations of 'restricted, repetitive patterns of behaviour, interests, or activities' [American Psychiatric Association, 2013, p.50], the nature and specificity of motor deficits in children with ASD remains unclear.

Behavioural studies have shown that children with autism display a range of motor deficits [e.g., Ghaziuddin & Butler, 1998; Jansiewicz, Goldberg, Newschaffer, Denckla, Landa, & Mostofsky, 2006]. Green et al. [2009] used a standardised motor battery, the Movement ABC [Henderson & Sugden, 1992], in a large, population-derived study of school-aged children with childhood autism and broader ASD, and found that 79% of the children with an ASD had definite motor impairments with a further 10% having borderline problems. Children with childhood autism (who had a lower average IQ) were more impaired than children with broader ASD, and children with an IQ of less than 70 were almost universally impaired in contrast to two-thirds of the children with an IQ of more than 70.

In addition, there is strong evidence that children/adults with ASD have marked difficulties with general praxis that extend beyond the commonly reported problems with the imitation of skilled motor gestures [e.g. Williams, Whiten & Singh, 2004]. Dziuk et al. [2007] compared the performance of 47 high-functioning children with ASD to 47 typically developing controls on a basic motor skills test, the Physical and

Neurological Assessment of Subtle Signs (PANESS) [Denckla, 1985], and a praxis examination which included gestures to command, to imitation, and with tool-use. They found that basic motor skill was a significant predictor of performance on the praxis assessment. Furthermore, they found that the correlation between praxis ability and social, communicative, and behavioural impairments remained after controlling for basic motor skill. In a study of gross motor skills in 35 children with high functioning ASD, MacDonald, Lord and Ulrich [2013] found a significant association, which was independent of IQ, between object-control motor skills, as measured by the Test of Gross Motor Development-2 [Ulrich, 2000], and a calibrated autism severity measure, based on the Autism Diagnostic Observation Schedule (ADOS) [Lord et al. 2000]. They concluded that weaker gross motor skills were associated with greater social communicative deficits in children with ASD.

These studies provide empirical evidence that children with ASD are at risk of a range of motor deficits which may impact on the emergence of social communication and social interaction skills. Furthermore, there is growing evidence that motor difficulties may be apparent from early childhood in children who are later diagnosed with ASD [e.g. Landa & Garrett-Mayer, 2006]. Leonard et al. [2014] used the Mullen Scales of Early Learning [Mullen, 1995] and the Vineland Adaptive Behaviour Scales [Sparrow, Cicchetti, & Balla, 2005] in a prospective study of 54 at-risk infants (who had an older sibling with a clinical diagnosis of ASD) and 50 low-risk infants (no family history of ASD). They found that the at-risk infants had lower motor scores on both measures as early as 7 months old, and that the development of fine motor skills was a particular difficulty for those at-risk children (n=17) who went on to develop ASD at 36 months. The nature and extent of the relationship between emerging

motor skills and cognitive/social functioning is still a matter of debate but it has been suggested that the acquisition of new motor skills in the first 18 months of life, such as object placement or crawling, plays an important role in the 'soft assembly' of recognitory gestures and joint attention (Iverson, 2010).

Although the implications of these studies may be important in the context of broadening intervention strategies beyond social skills training, it is not clear if the motor difficulties experienced by children with ASD are syndrome specific. Most studies of motor deficits in children with ASD either compare the motor profiles of the children with ASD to the standardised norms of a particular assessment battery or to a typically developing control group. Similarly, while there are a number of studies that have highlighted a range of neuropathological structural and functional abnormalities in children/adults with ASD [see review , Penn, 2007], the relatively few studies that have explored the neural correlates of motor functioning in this population have tended to use typically developing children/adults as controls. While abnormal activations in the cerebellum have been highlighted, [e.g. Allen, Müller & Courchesne, 2004; Mostofsky, Powell, Simmonds, Goldberg, Caffo & Pekar, 2009], it remains unclear if the motor anomalies that have been identified in these studies simply reflect a general level of underlying CNS dysfunction which may be common to a range of neurodevelopmental disorders. Gillberg (2010) has pointed out that neurodevelopmental disorders usually co-occur, and comorbidity may be the norm. Furthermore, the concept of 'atypical brain development' [ABD] [Gilger & Kaplan, 2001], suggests that neurodevelopmental profiles are likely to overlap, which implies that neurodevelopmental disorders may not represent discrete categories.

Cross-syndrome studies are an important method for identifying the specificity of observed atypicalities in behavioural or neural functioning across neurodevelopmental disorders [e.g. Karmiloff-Smith, 2012]. Dewey, Cantell, and Crawford [2007] compared the motor and gestural skills in 5 groups of children; children with ASD, children with developmental coordination disorder (DCD), children with DCD with attention deficit hyperactivity disorder (ADHD), children with ADHD without DCD, and typically developing children. They found that all of the atypically developing groups scored significantly lower than the typically developing group on a test of basic motor skills, the Bruininks-Oseretsky Test of Motor Proficiency Short Form [Bruininks, 1978], but that, irrespective of IQ, the children with ASD scored significantly lower than all of the other groups. They also found that the children with ASD scored significantly lower than all of the other groups on measures of gestural skill, irrespective of basic motor skills. These results are important as they suggest that children with ASD may have specific problems with basic motor and gestural skills which are distinct from other closely related disorders.

Similarly, Mostofsky, Burgess, and Gidley Larson [2007] examined the correlation between motor performance, as measured by the PANESS, with anatomic MRI measures in 20 children with autism, 36 typically developing (TD) controls and 20 clinical controls with ADHD. They found that children with autism had significantly higher impairment scores than both the TD and ADHD controls, and that the correlation between PANESS score and left motor cortex white matter volume in children with autism differed significantly from both the typically developing and ADHD children. The inclusion of a clinical group with close associations to autism in

this study provides strong evidence on the specificity of a possible motor neural correlate in children with ASD.

Motor difficulties in children with specific language impairment (SLI)

Verbal deficits in social communication and social interaction are a defining feature of ASD, and there is considerable evidence that social and communicative difficulties overlap in children with ASD and children with specific language impairment (SLI) [e.g. Conti-Ramsden, Simkin, & Botting, 2006; Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008].

It is thought that children with SLI have particular difficulties with the structural components of language (e.g. poor phonological and syntactical skills), while children with autism who develop language struggle with pragmatics (appropriate use of language in context) [e.g. Frith, 2003]. However, there is evidence to suggest that the distinction between the language skills of children with higher-functioning autism and children with SLI is less clear-cut. Some studies have shown that children with HFA have equivalent or more severe difficulties with the structural aspects of language than children diagnosed with language impairments [e.g. Bartak, Rutter & Cox, 1975], while other studies have shown that some children with SLI have significant pragmatic language difficulties in the absence of social deficits [e.g. Bishop & Norbury, 2002].

There is also growing evidence that children with SLI are at risk of motor difficulties [see reviews; Hill, 2001; Rechetnikov and Maitra, 2009], and that there are significant

overlaps in the motor profiles of children with SLI and children diagnosed with developmental coordination disorder (e.g. Hill, 1998). Finlay and McPhillips (2013), in a recent study which included 38 children with a clinical diagnosis of SLI, found that 32% of the SLI sample had 'definite motor problems' as defined by the Movement Assessment Battery for Children-2 [Henderson, Sugden & Barnett, 2007].

However, there is little work comparing the motor profiles of children with ASD and children with SLI. Mandelbaum et al. [2006] examined the prevalence of 'soft' motor deficits, using the PANESS, in 4 groups of children; children with developmental language disorder with average nonverbal IQ, children with autism (with average nonverbal IQ or low nonverbal IQ) and typically developing children with low nonverbal IQ. They found that while nonverbal IQ was the main functional discriminator, with low IQ associated with more deficits, there was evidence from qualitative impressions that more children with developmental language problems had deficits in sensorimotor and oromotor skills than children with autism with average nonverbal IQ. Noterdaeme, Mildenberger, Minow & Amorosa [2002] compared the performance of 11 children with childhood autism, 11 children with an expressive language disorder, 11 children with a receptive language disorder and 11 controls on a standardised neurological examination procedure which was used to calculate a 'global neuromotor impairment score'. All of the children had a non-verbal IQ above 85. They found that the motor problems experienced by the children with autism and the children with language disorders appeared similar although the relatively small group size meant that a finer grain analysis was not possible.

The Present Study

In summary, while a number of studies have shown that children with autism experience a range of motor difficulties, it is not clear to what extent these difficulties are autism specific, or to what extent they are similar to the motor difficulties shown by children with SLI. The primary purpose of the present study was to examine how far the motor deficits experienced by children with autism are syndrome specific using a standardised behavioural motor measure.

Method

Participants and design

An independent groups design was used. We selected 28 children (25 males; mean age 9 years 11 months, SD 8 months, range 33 months) from 2 special schools with classes for children with autism spectrum disorders (ASD) as the ASD group; we selected 27 children (26 males; mean age 9 years 7 months, SD 10 months, range 26 months) from a special school for children with specific language impairment (SLI) as the SLI group, and we selected 28 children (28 males; mean age 9 years 4 months, SD 8 months, range 27 months) from 2 mainstream schools as the typically developing (TD) group. The TD group was matched to the ASD and SLI groups on nonverbal IQ.

The schools were situated in the Greater Belfast district. All of the children with ASD and SLI had completed a formal educational statementing process detailing their specific difficulties. The statementing process in N Ireland involves 5 stages, and includes formal assessments by educational and clinical psychologists, in consultation with other appropriate specialists and medical staff. The statementing process can take up to several years to complete, and the assignment of diagnostic categories was

based on the relevant DSM-IV [American Psychiatric Association, 2000] criteria at the time of the study.

We used free school meal entitlement as an index of social disadvantage, and the proportions of children receiving free school meals were 43%, 30% and 64% for the ASD, SLI and TD groups respectively. The proportion of children receiving free school meals in the total primary school population in Northern Ireland at the time of study was 22% (Department of Education, Northern Ireland, 2010/2011).

Measures

The Social Responsiveness Scale (SRS) [Constantino & Gruber, 2005] was used to highlight children with a possible autism spectrum disorder, and was completed by the appropriate teacher for each child. An overall score of 59 or less is considered within the typically developing range. A score of 60-75 is considered to be in the moderate range, indicating less severe or high functioning autism. A score of 76 and above is considered indicative of autism and would warrant further investigation. Correlation coefficients greater than 0.64 between scores on the SRS and the Autism Diagnostic Interview Revised (ADI-R) suggest that the SRS is a valid assessment of autism severity [Hilton, Wente, LaVesser, Ito, Reed, & Herzberg, 2007]. The ASD group had a mean score of 76.5 (SD 5.9, range 26) on the SRS which provides support for the ASD diagnosis which had been assigned to these children.

The Wechsler Nonverbal Scale of Ability (WNV) [Wechsler & Naglieri, 2006] was used to measure nonverbal IQ. This test was particularly appropriate for a sample

with language difficulties as it makes use of pictorial directions throughout, eliminating verbal content.

The British Picture Vocabulary Scale 2 (BPVS-2) [Dunn, Dunn, Whetton, & Burley, 1997] and the Expressive Vocabulary Test 2 (EVT-2) [Williams, 2007] were used to assess receptive and expressive vocabulary respectively. The Children's Communication Checklist (CCC–2) [Bishop, 2003] was completed by the appropriate teacher for each child. Two composite scales; the General Communication Composite (GCC) and the Social Interaction Deviance Composite (SIDC), were calculated. The GCC provides a measure of language communication skills while the SIDC provides evidence of disproportionate pragmatic difficulties. On the GCC, scores below 54, 45 and 40 represent the bottom 10%, 5% and 3% of children respectively. On the SIDC, scores below 0 suggest an 'autism spectrum communication profile' whereas those scores above 8 suggest an 'SLI communication profile' [Bishop, 2003].

The Conners 3 (Teachers Short Form) [Conners, 2008] was used as a measure of ADHD level and was also completed by the appropriate teacher . The 'inattention' and 'hyperactivity/impulsivity' scales only were used in this study as they were thought to be most indicative of ADHD. Scores above 70 indicate clinically significant difficulties in these areas.

The Movement Assessment Battery for Children 2 (MABC-2) [Henderson, Sugden & Barnett, 2007] was used to assess the children's fine and gross motor skills. The test battery consists of 3 component areas with a total of 8 subtests; 3 tests of manual dexterity, 2 tests of aiming and catching, and 3 tests of static and dynamic balance.

The raw scores for each individual subtest are converted to a standard score which can be used to create an overall standard score for the relevant component, which is then converted to an overall Total Test standard score. The mean standard score for all elements of the MABC-2 is 10 with a standard deviation of 3. According to the MABC-2 test manual, scores in the bottom 5% (standard score of 5 or below) represent a definite motor problem requiring motor intervention, and scores between 5% and 15% suggest a degree of difficulty that is borderline [Henderson, Sugden & Barnett, 2007].

Procedure

Ethical approval for the study was granted by the Research Ethics Committee, School of Psychology, Queen's University, Belfast.

Parental and participant consent were obtained for each child prior to testing. From an initial sample of 147 children, it was possible to construct 3 groups of children representing an ASD group, an SLI group matched to the ASD group on nonverbal IQ and language scores (as initially assessed by the BPVS-2), and a typically developing (TD) control group matched to the ASD and SLI group on nonverbal IQ. The participants in both the SLI and TD groups were matched at group level to the ASD group as there was considerable variability in the language and nonverbal IQ profiles of the children with ASD. Participants were tested individually on all measures within their own school. All of the testing took place in a separate, quiet room in each school.

The assessments were conducted in three phases. All children completed Phase 1 where nonverbal IQ was assessed using the WNV [Wechsler & Naglieri, 2006]. Children with nonverbal IQs below 70 were excluded at this stage. In Phase 2 receptive language skills were assessed using the BPVS-2 [Dunn et al., 1997], and the appropriate class teacher completed the Social Responsiveness Scale (SRS) [Constantino & Gruber, 2005] for each child. The results from Phases 1 and 2 were used to construct the three groups, with the SLI group matched to the ASD group on nonverbal IQ and BPVS-2 scores. The TD group was also matched to the ASD and SLI groups on nonverbal IQ scores. Some children with below threshold (60) SRS scores from the ASD group and some children with above threshold SRS scores from the SLI and TD groups were excluded. The assignment of the children to the 3 groups is illustrated in Figure 1.

Insert Figure 1.

The children in each of the 3 groups then completed Phase 3. In Phase 3, the children completed the EVT-2 [Williams, 2007], and the MABC-2 [Henderson, Sugden & Barnett, 2007]. The appropriate class teacher completed the Children's Communication Checklist (CCC–2) [Bishop, 2003] and the Conners 3 (Teachers Short Form) [Conners, 2008] for each child.

Data Analysis

We used the SPSS 16.0 statistical package (SPSS Inc., Chicago, IL, USA) to analyse the data. We used standard MANOVA and ANOVA procedures to evaluate group differences, and correlation analysis to examine the relationships between the

measures for each group. An *a priori* calculation of statistical power, assuming an effect size of 0.4, suggested that 3 groups of 25 participants each would provide 86% power to detect a significant difference (G*Power 3) [Faul, Erdfelder, Lang, Buchner, 2007].

Results

Group characteristics

The group means and summaries of the ANOVA analyses for all of the group characteristics are shown in Table 1.

Insert Table 1

One-way between groups ANOVAs showed that there were no significant differences between the groups in age, $F(2, 80) = 1.428$, $p = .247$, or nonverbal IQ (Wechsler Nonverbal IQ Test(WNV)) [Wechsler & Naglieri, 2006] scores, $F(2, 80) = .163$, $p = .850$.

A one-way ANOVA showed that there was a significant main effect of group on SRS scores, $F(2, 80) = 292.289$, $p < .001$. Post hoc multiple comparisons indicated that the ASD group had significantly higher scores than the SLI ($p < .001$) and TD ($p < .001$) groups, while there was no significant difference between the SLI and the TD groups ($p = .761$).

One way ANOVAs showed that there was a significant main effect of group on; receptive language (BPVS-2) scores, $F(2, 80) = 6.679$, $p < .002$; expressive language

(EVT-2) scores, $F(2, 80) = 6.246$, $p = .003$, and on the GCC, $F(2, 80) = 3.571$, $p = .033$, and SIDC, $F(2, 80) = 9.643$, $p < .001$, scores from the CCC-2. Post hoc multiple comparisons indicated that the ASD and SLI groups had significantly lower receptive language ability than the TD group ($p = .013$ and $p = .004$, respectively). There was no significant difference between the ASD and SLI groups in receptive language ability ($p = 1.000$). (Post hoc multiple comparisons indicated a similar pattern for expressive language ability.) Post hoc multiple comparisons indicated that the SLI group had significantly lower GCC scores than the TD group ($p = .028$), while there were no significant differences between the SLI and ASD groups ($p = .797$) or between the ASD and TD groups ($p = .366$). Post hoc multiple comparisons indicated that the ASD group had significantly lower SIDC scores than the SLI group ($p < .001$), while there were no significant differences between the ASD and TD groups ($p = .559$) or between the SLI and TD groups ($p = .053$).

The distribution of nonverbal IQ, receptive and expressive vocabulary scores are further illustrated in Figure 2.

Insert Figure 2.

One-way ANOVAs showed that there was no significant difference between the groups on the 'inattention' subscale of the Conners 3, $F(2, 80) = 2.731$, $p = .071$, but that there was a significant difference between the groups on the 'hyperactivity/impulsivity' subscale, $F(2, 80) = 6.161$, $p = .003$. Post hoc multiple comparisons indicated that the TD group had significantly higher 'hyperactivity/impulsivity' scores than the SLI group ($p = .002$), while there were no

significant differences between the ASD and SLI groups (p = .171) or between the ASD and TD groups (p = .336).

Movement ABC-2 standard scores

The group means for the total and subtest scores on the MABC-2 and summaries of the ANOVA analyses according to group are shown in Table 2.

Insert Table 2.

Exploratory analyses revealed that the skewness values for all of the MABC-2 scores were within an acceptable range indicating the normalcy of the data; 0.71, 0.37 and 0.28, for the ASD, SLI and TD groups, respectively.

A one-way between groups ANOVA showed that there was a significant main effect of group on the total MABC-2 standard scores, $F(2, 80) = 10.595$, $p < .001$. Post hoc multiple comparisons showed that the TD group had significantly higher total MABC-2 standard scores than the ASD (p = .002) and SLI ($p < .001$) groups while there was no significant difference between the ASD and SLI groups (p = .959).

The distribution of total MABC-2 scores is further illustrated in Figure 3.

Insert Figure 3.

MANOVA revealed that there was a significant main effect of group on the MABC-2 subtest measures, Pillai's trace (V) = .495, $F(16, 142) = 2.916$, $p < .001$. The

ANOVAs showed a significant main effect of group on mean standardised score on the subtests of Manual Dexterity 2, $F(2, 77) = 6.055$, $p = .001$, Aiming and Catching 1, $F(2, 77) = 8.392$, $p = .001$, Aiming and Catching 2, $F(2, 77) = 7.035$, $p = .002$, Balance 1, $F(2, 77) = 5.596$, $p = .005$, Balance 2, $F(2, 77) = 3.674$, $p = .030$, and Balance 3, $F(2, 77) = 7.311$, $p = .001$. There was no significant main effect of group on Manual Dexterity 1, $F(2, 77) = 1.498$, $p = .230$, or Manual Dexterity 3, $F(2, 77) = 2.435$, $p = .094$.

Manual Dexterity 2 (Threading lace)

Post hoc multiple comparisons revealed that the ASD group was significantly slower on this task than the SLI and TD groups ($p = .019$ and $p = .002$, respectively). There was no significant difference between the SLI and TD groups ($p = 1.000$).

Aiming and Catching 1 (Throwing and catching a ball)

Post hoc multiple comparisons revealed that the ASD and SLI groups made significantly fewer catches than the TD group ($p = .002$ and $p = .002$, respectively). There was no significant difference between the ASD and SLI groups ($p = 1.000$).

Aiming and Catching 2 (Throwing a bean bag onto a mat)

Post hoc multiple comparisons revealed that the ASD group made significantly fewer successful throws than the TD group ($p = .001$). There were no significant differences between the SLI and TD groups ($p = .054$) or between the ASD and SLI groups ($p = .661$).

Balance 1 (One-board balance)

Post hoc multiple comparisons revealed that the ASD and SLI groups had significantly shorter balance times than the TD group (p = .019 and p = .011, respectively). There was no significant difference between the ASD and SLI groups (p = 1.000).

Balance 2 (Walking heel-to-toe, forwards)

Post hoc multiple comparisons revealed that the ASD group made significantly fewer successful steps than the TD group (p = .038). There were no significant differences between the SLI and TD groups (p = .124) or between the ASD and SLI groups (p = 1.000).

Balance 3 (Hopping on mats)

Post hoc multiple comparisons revealed that the SLI group made significantly fewer successful hops than the TD group (p = .001). There were no significant differences between the ASD and TD groups (p = .069) or between the ASD and SLI groups (p = .378).

Correlations

Correlation analyses were conducted in order to examine the relationship between total MABC-2 scores and measures of social responsiveness, nonverbal IQ, and the measures of language functioning for each group. A correlation matrix is shown in Table 3.

Insert Table 3.

The analyses revealed that the correlations between a composite language measure (GCC) and the MABC-2 scores were significantly, positively correlated for the ASD and SLI groups, while the GCC scores were significantly, negatively correlated to SRS scores for the ASD and TD groups. In contrast, the correlations between social responsiveness scores (SRS) and basic motor skills (MABC-2) scores for each group were very low. Together, these correlations suggest that, in children with autism spectrum disorder, higher language communication skills may be associated with improved levels of basic motor skills and improved social responsiveness.

Discussion

The overall findings of the present study indicate that children with ASD and children with SLI have significant deficits in a range of motor skills relative to typically developing children of the same age and nonverbal IQ. The results have major clinical implications as 61% of the ASD sample scored in the bottom 15% of a standardised motor assessment (MABC-2), with 50% scoring in the bottom 5%, while 52% of the SLI sample scored in the bottom 15%, with 33% scoring in the bottom 5%. For the group of typically developing (TD) children, 8% scored in the bottom 15%, with 4% scoring in the bottom 5%. Scores in the bottom 5% are thought to represent a definite motor problem requiring motor intervention, while scores between 5% and 15% suggest a degree of difficulty that is borderline [Henderson, Sugden & Barnett, 2007].

However, it is also apparent that there is within-syndrome variability for the ASD and SLI groups on all of the motor and language measures with some scores extending into the typical range. Conversely, some of the scores for the TD group on the same

measures extend into the atypical range. It was beyond the scope of the present study to determine if within-syndrome variability represented particular sub-groupings within each group or to what extent the variations highlight the dimensional nature of developmental disorders as suggested by neuroconstructivist developmental models [e.g. Gilger & Kaplan, 2001; Karmiloff-Smith, 2012], which emphasise the interaction of multiple developmental processes over time.

Previous work has suggested that children with autism may have particular problems with the 'ball skills' and 'balance' component areas of the MABC [e.g. Green, Baird, Barnett, Henderson, Huber, & Henderson, 2002]. In the present study, using the more recent MABC-2 test battery, the ASD group scored significantly lower than the TD group in both of these component areas, but the SLI group had a very similar level of deficit across both areas as well. These findings suggest that some of the motor difficulties of children with ASD that have been described in previous work may not be autism specific.

Analysis of the 8 specific subtests, which make up the broader composite areas of the MABC-2, was used to provide a detailed, comparative motor profile of the children with ASD, and SLI, in the present study. One of the most striking features of this analysis was that the children with ASD had a very similar pattern of motor deficits to the children with SLI across most of the motor areas assessed, with one exception; there was a significant difference between the ASD and SLI groups on a threading task (manual dexterity 2). Unlike the other two manual dexterity tasks, the threading task involves the coordination of both hands at the same time, and this was particularly problematic for the children with ASD. Further work is required to

determine the nature of this difficulty in children with ASD, including the particular cognitive and motor demands and associated motor/cognitive neural systems. Mostofsky et al [2009] have shown that increased left hemisphere primary motor and premotor white matter volume is associated with motor problems in children with autism, and MRI studies have reported reductions in the size of the corpus callosum in autism [e.g. Piven, Bailey, Ransom, & Arndt, 1997]. It is not clear if such potential structural problems interfere with the smooth execution of complex bi-manual tasks.

While there was only a significant difference between the ASD and SLI groups on the threading task (manual dexterity 2), the SLI group showed marked difficulties with the drawing a trail subtest (manual dexterity 3), where a line is drawn within boundaries. In fact, the ASD group actually made, on average, fewer errors than the TD group on this task. This suggests that more detailed analysis of the fine motor skills of children with ASD, and SLI, is needed.

There was one significant language difference between the ASD and SLI groups. On the Social Interaction Deviance Composite (SIDC) scores of the Children's Communication Checklist (CCC-2) [Bishop, 2003], the children with ASD were rated as having significantly disproportionate pragmatic difficulties in comparison to the children with SLI by their respective teachers. The SIDC scale is a measure of difference between general communication (structural) language skills and social interaction (pragmatic) language skills. In addition, the correlation analyses suggest that the relationship between language attainments and basic motor skills is not straightforward. While the correlations between some of the language measures (BPVS-2, EVT-2, SIDC) and the MABC-2 scores were small, there was a significant

correlation between the General Communication Composite (GCC) and MABC-2 scores for the ASD and SLI groups. This suggests that overall language communication skills may be more related to basic motor skills than isolated, specific elements of language, such as receptive or expressive vocabulary. It also provides further evidence that language functioning in children with ASD and children with SLI is closely related to the attainment of basic motor skills.

The strong similarity between the motor deficits of children with ASD and children with SLI in this study does not necessarily mean that the underlying causal mechanisms are the same for both groups of children. Children with autism may share common language difficulties with children with SLI, but some recent family studies suggest that the similarities between language deficits in both disorders may not reflect a shared aetiology [e.g. Whitehouse, Barry & Bishop, 2007]. This may also be the case for motor deficits as well. Cross-syndrome studies, which examine the behavioural and neural associations of motor functioning in children with ASD and SLI, are needed in order to identify the potential overlaps in underlying causal mechanisms.

The three study groups had relatively high scores on the attention-deficit-hyperactivity disorder (ADHD) measure, and ADHD has been shown to be associated with motor coordination problems in children [e.g. Kadesjo & Gillberg, 2001; Cairney, Veldhuizen & Szatmari, 2010]. In the present study, the TD group had slightly higher scores than the other two groups on both the inattention and hyperactivity/impulsivity scales. The three study groups also had relatively high

levels of free school meal entitlement, which is commonly used as a marker of social disadvantage.

It may be worth noting that the scores for the TD group on the 3 manual dexterity measures of the MABC-2, which measure fine motor skills, were markedly below the population mean. As mentioned earlier, the ASD group actually scored higher than the TD group on one of these tests (drawing a trail, manual dexterity 3). It should also be noted that the TD group had low average scores on all of the language measures used in this study. Social disadvantage has been highlighted as a powerful risk factor for delayed language and motor development [McPhillips & Jordan-Black, 2007], and the significant advantage of the TD group relative to the ASD and SLI groups on most of the language and motor measures used in this study may have been even more marked if the groups had been more balanced in terms of socioeconomic status (SES).

Limitations

The MABC-2 is a task based motor measure, and it is possible that two children may obtain the same scores on any of the subtests using very different motor strategies, or that similar motor profiles reflect different interactions between neurological and environmental factors. Further research is required to compare, for example, the movement kinematics of children with ASD and children with SLI while completing specific movements, and longitudinal comparisons of both groups of children may reveal specific early neurological markers associated with delayed motor development as well as differential motor experiences. The dynamic interaction of neurobiological,

cognitive, and environmental factors on motor and language functioning over developmental time cannot be fully captured in cross-sectional studies.

Implications and Future Directions

The present study provides further evidence that motor deficits are relatively common in children with ASD, and SLI. This has implications for the development of clinical assessment procedures, which should acknowledge the broader profile of both groups of children, and for the integration of appropriate motor intervention strategies, which could complement the current emphasis on social and language skills training. Family and longitudinal studies may provide more insight as to possible overlapping genetic and environmental influences on motor development in children with ASD and children with SLI, and possible associations with language development.

Children or adults with motor difficulties (e.g. developmental coordination disorder (DCD)) have been used as controls in previous work. However, one of the key findings of the present study is that motor deficits in children with ASD may be associated with language skills. This suggests that children with SLI should also be included as a standard control group for behavioural and neurological studies of motor skills in children or adults with ASD in order to identify autism specific motor deficits.

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