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ORIGINAL PAPER

Exploring the Relationship Between Gestural Recognition and Imitation: Evidence of Dyspraxia in Autism Spectrum Disorders

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Abstract In this study, the relationship between gesture recognition and imitation was explored. Nineteen individuals with Autism Spectrum Disorder (ASD) were compared to a control group of 23 typically developing children on their ability to imitate and recognize three gesture types (transitive, intransitive, and pantomimes). The ASD group performed more poorly than controls on all tasks of recognition and imitation. Higher performance on tests of working memory was associated with increased odds of successful imitation in both groups. Group differences remained even when working memory was statistically controlled for. An association was revealed in the ASD group between pantomime recognition and imitation but a similar association was not identified for intransitive gestures suggesting that recognition alone is not sufficient for imitation success.

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Introduction

Imitation is a social, neurological, and biological phenomenon that is considered theoretically and clinically relevant to diverse patient populations including children with developmental disorders and adults with acquired brain lesions. Imitation research has focused on two clinical groups in particular: Individuals with autism spectrum disorder (ASD) and adult patients with limb apraxia. Limb apraxia is a deficit of processing purposeful movements, unexplained by sensory or motor deficits. In the pediatric literature, the term developmental dyspraxia is often used in place of the term apraxia. Although the former is typically an acquired disorder and the latter is a developmental disorder, in recent years the focus has shifted away from describing the differences between the two groups, and towards embracing the similarities and applying new knowledge to the pediatric populations (Cermak et al. 2002; Dewey et al. 2007; Sanger et al. 2006; Smith and Bryson 1994). Disentangling imitation and dyspraxia is an important area of research in autism, and one that may further inform the understanding of underlying cognitive mechanisms necessary for successful imitation.

Traditionally, imitation in autism has been investigated in the context of cognitive theories. Earlier studies in imitation focused on an underlying disorder of symbolic representation in individuals with autism (Ohta 1987). Later, the self-other mapping hypothesis suggested that a primary deficit in imitation created a cascading effect resulting in the lack of development of symbolic thinking, emotion-sharing, joint attention, and theory of mind

(Rogers and Pennington 1991). The mirror neuron theory extended the self-other mapping hypothesis, implicating the faulty development of the mirror system in imitation impairments in individuals with ASD.

The mirror neurons were first identified over two decades ago as those visuo-motor neurons that fire under two conditions: both when the monkey performed an action and when it observed another individual performing the same action (Rizzolatti et al. 2001; Di Pellegrino et al. 1992). There are reasons to believe that mirror neurons are also present in humans; indeed, functional neuroimaging studies have provided evidence that the prefrontal cortex may be involved in a "motor resonance" between the observation of an action and the execution of the same action (see Rizzolatti and Craighero 2004, for a review). If gesture observation and comprehension partly rely on the same mechanism necessary for its imitation, as would be predicted by MNS theory, a correlation between recognition and imitation of gestures would be expected (Umiltà et al. 2001). In individuals with autism, it has been proposed that the imitation deficit may be the result of abnormal mirror neuron development that in turn, is also responsible for the deficits in self-other mapping, as well as the impairment in social cognitive skills (Oberman and Ramachandran 2007; Williams et al. 2001).

Williams et al. (2001) predicted specific patterns of imitation deficits in individuals with autism based on the MNS hypothesis; specifically, worse performance in the imitation of meaningless gestures (those not recognized as familiar); better imitation of actions with objects (possibly as a result of object affordances); and the presence of reversal errors ("recreating the hand view that they see instead of translating the perspective the other had seen": Williams et al. 2001, p. 8). However, recent research has highlighted discrepancies in these predicted patterns of imitation performance, including intact gesture recognition in individuals with autism (Hamilton et al. 2007; Hamilton 2008; Leighton et al. 2008).

In addition, imitation performance in autism appears to be task dependent and researchers have suggested that imitation should not be studied as a "single cognitive or neural system" (Hamilton et al. 2007, p. 1867) and that the MNS is "likely to subserve more than a single cognitive function" (Vogt et al. 2007, p. 1371). Moreover, observations that specific error patterns reported in individuals with ASD are similar to those in adult patients with limb apraxia, have prompted researchers to consider whether these fractionations within the gestural system in ASD may be more parsimoniously explained by a disorder of praxis processing, or apraxia, and not the mirror neuron system alone (Mostofsky et al. 2006). A selective impairment of intransitive gesture production has already been reported in an individual with autism (Stieglitz Ham et al. 2010).

Buxbaum et al. (2005) identified a correlation between pantomime recognition and imitation in patients with limb apraxia, in line with the MNS theory. However, studies of limb apraxia have found dissociations between gesture recognition and imitation. In particular, the discovery that patients with lesions in the parietal lobe present with both recognition and imitation errors whereas patients with anterior lesions demonstrate only imitation deficits and not recognition errors provided the foundation for the first cognitive neuropsychological model of praxis processing in adults (Rothi et al. 1991). This dual-route model allows for two independent routes of gestural processing; one responsible for the processing of meaningful gestures along the lexical route, and the other for the processing of meaningless gestures along the non-lexical route (Cubelli et al. 2000; Rothi et al. 1991). This model has been useful in explaining patterns of impairments in limb apraxia population, including a case described by Bartolo et al. (2001). The authors reported a case of a patient, MF, who showed a spared ability to recognize meaningful gestures coupled with an impaired ability to imitate the same gestures (Bartolo et al. 2001). The imitation deficit was not accounted for by a specific gesture reproduction disorder or motor impairment since the patient could imitate mean-ing*less* actions flawlessly. The authors suggested that once a gesture is recognized as familiar, it is imitated using the long-term memory information stored along a semantic (lexical) route; if it is not recognized as familiar it will be imitated through a mechanism that converts the visual information into a motor act (non-lexical route: Bartolo et al. 2001; Cubelli et al. 2006). Since the patient was also impaired in producing meaningful gestures on command, her lexical route was supposedly impaired at some point after the gestures were recognized.

Similarly, some studies suggest that individuals with autism do not demonstrate gestural recognition impairments, but do show imitation deficits (Hamilton et al. 2007; Smith and Bryson 2007). The findings that both limb apraxia patients and individuals with autism, lack an association between gesture recognition and imitation, go against the MNS hypothesis and support instead the hypothesis that gesture recognition is not sufficient for its imitation. According to the dual-route model, reproduction could depend upon a lexical route that can be affected even after the gesture is recognized. This theory is in line with electrophysiological studies that have found that the access of image based representations (i.e., a picture related semantic network) continues even after the semantic component has been accessed for meaningful gestures (Reid and Striano 2008).

In the present study, we examined praxis processing in ASD by assessing gesture recognition and imitation using transitive (i.e., actual object use), intransitive gestures (e.g., social gestures, like "waving"), and pantomimes (i.e., gestures that describe the object use) to explore the MNS theory and the dual-route hypothesis. If the ability to recognize gestures partly relies on the same mechanism for its imitation, as would be predicted by MNS theory, a correlation between recognition and imitation of gestures would be expected. If the imitation of meaningful gestures relies on two routes (a lexical route when gestures are recognized and non-lexical route when they are not recognized), then a correlation between recognition and imitation is not expected.

Impaired skills in social communication are well-documented in individuals with autism (Kanner 1943; Asperger 1944, cit. in Mayes et al. 2001; Wetherby et al. 2000); therefore, by employing tests of meaningful gesture recognition and imitation, we predict that individuals with autism will be more affected in the recognition of *intransitive* than in *object related* gestures (transitive and pantomimes). In line with the MNS hypothesis, impaired gesture recognition would be followed by difficulties in gesture imitation; whereas according to the dual-route models of cognitive processing in limb apraxia, intransitive gestures will be imitated as if they are meaningless, using the non-lexical route. For this reason, a correlation between the recognition and the imitation of intransitive (social) gestures is not expected. A correlation between the recognition and imitation of object-related gestures such as pantomimes or object use (transitive gestures) is predicted. Finally, several possible underlying cognitive functions that may influence imitation performance, including visual perception (VP), visual motor integration (VMI), intelligence, and tests of working memory [digit recall (DR), word list matching (WLM), and listening recall (LR)] were included in the assessment.

Method

Participants

Twenty-three children with Autism Spectrum Disorder (ASD) were recruited through the Autism Society of Southeastern Wisconsin. Four children were removed from consideration when they were later found to have concomitant diagnoses such as ADHD. The remaining 19 children had ages 7–15 (mean 12.1; SD 2.3), and were diagnosed with Asperger Syndrome ($N = 16$) or High Functioning Autism ($N = 3$), without any comorbid disorder. All children met DSM-IV (APA 1994) diagnostic criteria for Autistic Disorder or Asperger syndrome. Participants had their diagnosis reconfirmed using the Autism Diagnostic Observation Schedule (ADOS: Lord et al. 2002) by examiner H.S.H who was trained to administer the ADOS for research purposes. Participants were only included in the ASD group if the communication and social interaction total scores exceeded 10 (mean ADOS total for included participants = 17.1, SD = 4.2, range = 12–26). Additionally, the Social Communication Questionnaire (SCQ: Rutter et al. 2003), was completed by the parents. An informal parent interview was also conducted. Participants mean SCQ score was 23.5, SD = 5.7 (range 15–34) and a score $\geq$15 is suggested by the authors as an indication of a possible ASD. These participants were tested either in their homes or in the Division of Neuropsychology, Department of Neurology at the Medical College of Wisconsin.

Twenty-three typically developing children (TD) were recruited through community resources and tested in their homes. They were matched to the originally-recruited ASD group for age (range 7–15 mean 12.0; SD 2.1), gender, Verbal Intelligence (VIQ), Performance Intelligence (PIQ), and Full Scale Intelligence (FSIQ). IQ was measured using the Wechsler Abbreviated Scales of Intelligence (Wechsler 1999). *T*-tests were performed on each variable between the 19 ASD and 23 TD participants. There were no any significant group differences on the matching criteria between the two groups [VIQ, PIQ, FSIQ, and Chronological Age all above significance level using equal variance *t*-test, $p =$ ns], and for this reason all 23 TD participants were included in further analyses. Table 1 provides details of the group characteristics.

Preassessment Measures

All participants underwent a general neuropsychological preassessment. Visuo-motor coordination was assessed using the Beery Visual Motor Integration Test (VMI), and the Beery Visual Perceptual Subtest (VP: Beery and Beery 2004), which require participants to copy or match geometric shapes of increasing complexity respectively. Three measures from the Working Memory Test Battery for Children were administered (Pickering and Gathercole 2001): Digit recall, word list matching, and listening recall. The digit recall task required participants to repeat back series of verbally presented numbers. The word list matching task required participants to report whether two auditorily-presented lists of words were in the same order. Both of these measures test the Phonological Loop. In the listening recall task, a test measuring the Central Executive, participants judged whether lists of sentences were true or false, before recalling the final word of each sentence.

Participants did not differ on VP; however, ASD participants performed significantly worse on VMI [$t_{40} = -3.91$, $p < .001$, Cohen's $d = -1.23$] compared to the typically developing group. For the working memory tests, participants with ASD did not differ from the typically developing control group on the test of digit recall, but they

Table 1 Demographical data and IQ measures of the TD and ASD groups

Participants		Age	Gender	IQ		
				Verbal	Performance	Full scale
TD ($N = 23$)	Range	7.3–15.8	21 M/2F	87–134	69–143	79–139
	Mean (SD)	12.0 (2.1)		107.5 (12.9)	112.8 (18.8)	111.4 (16.5)
ASD ($N = 19$)	Range	7.58–15	17 M/2F	81–144	72–155	79–153
	Mean (SD)	12.1 (2.4)		106.0 (19.0)	102.5 (22.7)	106.0 (21.0)

TD typically developing group, *ASD* autism spectrum disorder

Table 2 Measures of general neuropsychological assessment of the TD and ASD groups

Participants		VMI	VP	Working memory		
				Digit recall	Word list matching	Listening recall
TD ($N = 23$)	Range	78–136	19–30	71–145	77–143	68–126
	Mean (SD)	102.4 (13.4)	26.5 (2.5)	107.0 (21.6)	106.0 (16.2)	100.3 (16.8)
ASD ($N = 19$)	Range	72–109	20–30	71–141	70–120	66–109
	Mean (SD)	87.6 (10.4)	25.8 (2.6)	98.6 (20.2)	91.8 (15.1)	85.7 (12.9)

TD typically developing group, *ASD* autism spectrum disorder, *VMI* visual motor integration, *VP* visual perception

did perform significantly more poorly on the tests of word list matching and listening recall, [$t_{40} = -2.91$, $p = .006$, Cohen's $d = -.90$ and $t_{40} = -3.08$, $p = .004$, Cohen's $d = -.97$ respectively]. Table 2 provides characteristics of the pre-assessment measures for both groups.

Apraxia Tasks

The experiment was designed to test the imitation and recognition of transitive gestures (actions involving objects), intransitive gestures (actions without objects but with symbolic meaning), and pantomimes (mimes of object use). In order to assess apraxia in a population of individuals with ASD, a new battery of tasks was developed. This battery was based on tests used in adult apraxia research (Bartolo 2002; Bartolo et al. 2008; Buxbaum et al. 2005) but was substantially altered to make the tasks appropriate and engaging for the target developmental level.

Stimuli were adapted and designed for computer administration. Each stimulus comprised a pre-recorded videoclip, used to ensure the consistency of the presented stimuli so that all participants viewed identical executions of each gesture. The videoclips showed the upper bodies of actors performing gestures and/or using objects. The stimuli used in the videoclips included common gestures that were familiar to school-aged children and adolescents. All gestures were meaningful (they showed realistic uses of objects, or hand movements with symbolic meaning). Where these gestures included (real or imaginary) objects, the objects depicted were everyday household items.

Recognition Tasks

The transitive gesture recognition task comprised 10 videoclips of actors correctly using common objects, and 10 videoclips showing incorrect object use. The intransitive gesture task was made up of ten examples of actors performing communicative gestures correctly, and ten examples of actors performing meaningless gestures. The pantomime recognition task comprised 20 videoclips of actors miming object use. In 10 clips, the objects were used in a conventional way, and in 10 clips, the object use was ‘wrong’ (e.g., bringing an imaginary spoon to the nose instead of the mouth). An example clip was also created for each gesture type. A full list of imitation and recognition stimuli is given in Appendix 1.

Imitation Tasks

Stimuli for the imitation of transitive gestures comprised 20 videoclips of actors correctly demonstrating common object use; in the intransitive gesture imitation task, actors correctly performed 20 communicative gestures; the pantomime imitation task used 20 videoclips of actors pretending to use imaginary objects. In addition, an example clip was created for each task.

Procedure

For all six tasks, participants were seated opposite the computer monitor/laptop screen in a quiet room. Participants were informed that they would view a series of videoclips of people using objects or performing gestures with their hands. The instructions provided were designed to be short and direct using an appropriate developmental language level.

Recognition

At the beginning of each recognition task, participants were shown an example videoclip. For the recognition of object use, the participants were asked to state if the person in the videoclip was using the object correctly or incorrectly. In the pantomime recognition task, the participants were asked to state if the person in the videoclip was *pretending* to use the object correctly or incorrectly. Finally, in the recognition of intransitive gestures task, the participants were asked to determine if the gesture in the videoclip was familiar or not by saying 'yes' if they had seen it before and 'no' if they had not. Participants proceeded to view 20 clips in each task. Once the example clip had been viewed, feedback was given for motivation but not accuracy. The total number of correct judgements (out of a maximum 20) was recorded for each task.

Imitation

Three imitation tasks were administered: Transitive gestures, intransitive gestures, and pantomimes. At the beginning of each task, participants were shown an example videoclip. After this had been viewed, the experimenter instructed the participant to "do what he/she just did," and provided feedback where necessary. Participants were instructed to imitate the clip twice, once with each hand. After the example clip, the experimental clips were shown in sequence. Participants began imitating at the end of each videoclip. Each stimulus was shown a maximum of two times, without penalties in case the imitation was correctly carried out the second time. During the experimental sessions, feedback was given for motivation but not for accuracy. Each imitation task ended when all 20 stimuli had been viewed. Maximum score for each hand and each gesture was 20. During the imitation tasks, all of the participants' gestures were video-recorded for subsequent coding and analysis. The coding system followed error code descriptions used in previous studies of apraxia in adults (Bartolo et al. 2008; Buxbaum et al. 2005) and included new codes created by the examiner, H.S.H to capture autism unique error patterns that may have otherwise been overlooked. The coding system measured the number and types of errors present during an incorrect imitation trial (see Appendix 2).

Results

Approach to Analysis

The recognition and imitation data analyses were performed in five consecutive steps: Evaluating group differences in task performance; comparing task performance across gesture types in both groups; predicting underlying cognitive mechanisms necessary for recognition and imitative performance; assessing error types; and exploring correlations and relationships between recognition and imitation tasks.

Group Differences

Welch's independent *t*-tests were used to determine group differences in the performance of recognition and imitation tasks for all three gesture types. Welch's *t*-tests were selected over Mann–Whitney *U* tests as the analysis of choice to account for the unequal variances in the tested samples.

Results of the recognition and imitation tasks showed significant between-group differences, revealing poorer performance of the ASD participants on all tasks of *recognition* [transitive gestures $t_{39.9} = -4.67$, $p < .001$, Cohen's $d = -1.54$; intransitive gestures $t_{27.09} = -5.20$, $p < .001$, Cohen's $d = -1.63$; and pantomimes $t_{22.68} = -2.53$, $p = .019$, Cohen's $d = -.76$]. Similarly, the TD group outperformed the ASD group in all of three tasks of *imitation*: [transitive gesture imitation $t_{18.9} = -6.52$, $p < .001$, Cohen's $d = -2.17$; intransitive gestures $t_{19.8} = -7.4$, $p < .001$, Cohen's $d = -1.29$; and pantomime imitation $t_{21.2} = -7.9$, $p < .001$, Cohen's $d = -2.5$]. Table 3 summarizes each group's performance in each of the tasks.

Table 3 Results achieved at the recognition and imitation tasks of the ASD and TD groups

	Autism spectrum disorder ($n = 19$) (mean ± sd)	Typically developing ($n = 23$) (mean ± sd)
Recognition		
Object use***	18.1 ± .69	19.3 ± .81
Intransitives***	14.1 ± 2.35	17.2 ± 1.3
Pantomimes**	15.9 ± 3.47	18.1 ± 1.4
Imitation		
Object use***	12.4 ± 4.52	19.3 ± .81
Intransitives***	13.1 ± 3.73	19.5 ± .92
Pantomimes***	9.3 ± 5.03	18.9 ± 1.7

Asterisks indicate differences between groups; *** $t < .001$; ** $t < .01$

Order Effects

Paired sample *t*-tests were performed for each imitation type to determine if any differences in the two attempts could be attributed to practice effects. There were no effects for either transitive gestures or pantomimes, but order effects were observed in intransitive gesture imitation in the autism group only [$t_{18} = 3.2$, $p = .004$, Cohen's $d = .70$]. However, since this effect was opposite what would have been predicted by practice, we collapsed all three gesture types across the first and second attempts.

Recognition Performance Across Tasks

A logistic (binomial) regression model was fitted to analyze recognition task performance. Since no group-task interaction was evident, an additive model was used. We added cognitive variables to the model, to examine the effects of task, group, and cognitive variables on the log odds of successful recognition. The cognitive variables were included in the model to control for their effects on the performance outcome. The variables included Full-Scale IQ, Visual Perception, Visual Motor Integration, and three subtests of working memory including Listening Recall, Word List Matching, and Digit Recall. The results from the final model, in which all main effects and the significant interactions were included, are provided; high odds ratios indicate higher odds of success.

Compared to autistic children, typically developing children were 2.3 times more likely to recognize gestures successfully. Compared to pantomime recognition, intransitive gesture recognition was more difficult (odds-ratio [OR] = .62, $p = .001$), whereas object recognition was easier (OR = 2.6, $p < .001$). In the model, pantomime recognition was used as the statistical reference. This effect was similar in both groups, although the individuals with autism performed all tasks more poorly than the controls.

Imitation Performance Across Tasks

A second model of regression was conducted to assess the influences of group, task, and cognitive measures on performance in the three types of imitation tested. The cognitive variables were included in the model to control for their effect on the performance outcome. As in the recognition logistic regression model, the same cognitive variables were included in the analyses when the model was fitted. This logistic regression analysis was similar to the recognition model, and compared the tasks with each other using pantomime imitation as the statistical reference for comparison. No group-task interaction was evident, so an additive model was used. The results of this analysis revealed a large group difference, as well as smaller but significant differences between tasks. The odds of successful imitation amongst typically developing children were 19.5-fold higher than among autistic children ($p < .001$). The results indicated that the autism group performed all of the imitation tasks more poorly than the controls. In this case, pantomimes were performed worse than imitation of either transitive (OR = 1.86, $p = .003$) or intransitive (OR = 2.30, $p < .001$) gestures. See Fig. 1 for the imitation results.

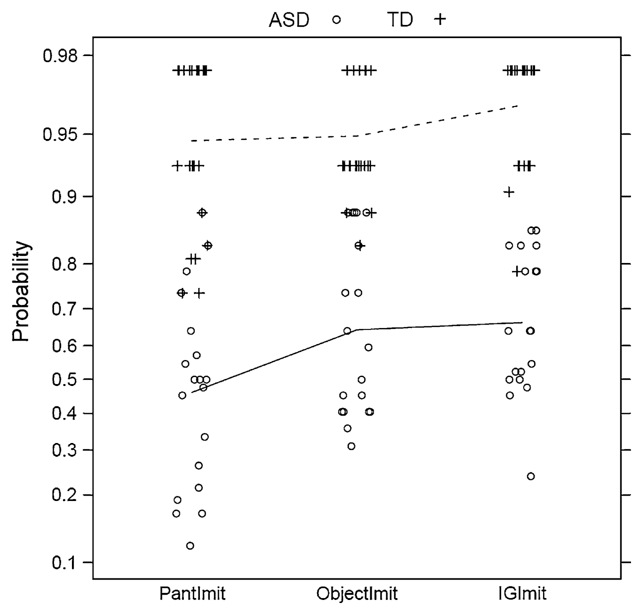

Fig. 1 TASK performance across gesture types for the ASD and TD groups

Interestingly, this effect and overall pattern of performance was similar in both groups. Although the overall difference in performance was not fully explained by the cognitive measures; higher Visual Perception and Listening Recall were associated with higher success while higher Digit Recall performance was associated with lower success. Word List Matching and Visual Motor Integration did not significantly predict success. The results support previous findings suggesting that while visual motor deficits are observed in individuals with autism, the imitation deficits are not explained by motor difficulties alone (Stieglitz Ham et al. 2008). See Table 4 for the model summary.

Age as a Predictor of Outcome

The ASD and TD groups were carefully age-matched, thereby controlling the effect of age on the outcome. However, to confirm that age did not affect the imitative performance of the groups, bivariate correlations were performed, comparing age with the results on the three imitation tasks. In

Table 4 Odds ratios in imitation task performance of both TD and ASD groups

Imitation task	OR	*p*-Value
Gesture type		
Pantomime (Reference)	1.00	Reference
Intransitive gesture vs. Pantomime	2.30	<.001
Object use vs. Pantomime	1.90	.003
Group		
ASD	1.00	Reference
TD	19.50	<.001
Visual perception	1.10	.004
Listening recall	1.04	.004
Digit recall	0.99	.005
Word list matching	1.00	.502
Visual motor integration	0.99	.258
Full scale IQ		
Within ASD	1.00	.961
Within TD	0.96	.021

the ASD group, the associations were not significant for intransitive gestures or pantomimes [ASD: $r_{19} = .320$, $p = .18$; $r_{19} = .402$, $p = .08$], but they were significant for the transitive gesture imitation task [$r_{19} = .567$, $p = .01$]. In the TD group, associations were not significant for transitive gestures, intransitive gestures, or pantomimes [$r_{23} = .200$, $p = .36$; $r_{23} = .038$, $p = .86$; $r_{23} = .254$, $p = .242$].

A follow-up regression model was fitted that included age as a cognitive variable. The results revealed that although age did have a significant effect [OR = 1.10, $p = .007$], it could not explain the dramatic difference between the imitative performances of individuals with ASD and typically developing children. The odds of successful imitation amongst typically developing children remained over 19.5-fold higher than amongst autistic children ($p < .001$).

Error Types

To investigate the errors contributing to the meaningful gesture imitative performance the percent of gestures with specific error types among all gestures with errors were calculated and binomial regression models were used to compare the error rates between the two groups. The following codes were used across all three tasks: Hand posture, arm/trajectory, amplitude, timing, and reversal errors. The pantomime errors also included body part as object and distance errors. In pantomime imitation there was a main effect of hand and reversal errors [$F_{1,28} = 5.0$, $p = .034$; and $F_{1,28} = 6.0$, $p = .021$] whereas in intransitive gesture imitation only amplitude errors significantly differed between the two groups [$F_{1,28} = .043$]. Similarly to pantomime imitation, significant findings were revealed between groups in transitive gesture hand errors [$F_{1,29} = 8.5$, $p = .007$]. Not all participants in the TD group made errors and only trials with errors could be used for analyses; therefore, low power may have been a factor as to why additional spatiotemporal errors were not statistically different between the two groups. See Appendix 2 for gesture coding.

Association Between Recognition and Imitation

To investigate the relationship between recognition and imitation, bivariate correlations were performed separately for the ASD and TD groups. A significant association between pantomime imitation and pantomime recognition was identified in the autism group [$r_{19} = .543$, $p = .01$] but not in the TD group. To compare pantomimes to the other gesture types, the same correlations were performed for object and intransitive gesture recognition and imitation in the ASD group and the results were not significant, suggesting that in ASD there may be a unique relationship between pantomime recognition and pantomime imitation.

Analysis of association between ADOS and SCQ scores and imitation

To explore the effect of ADOS and SCQ performance imitation success, two separate models were used to test for an interaction between ADOS and task and SCQ and task. Since no interaction was found, an additive model measuring the effect of ADOS and SCQ on gesture imitation was fitted. The results indicated that higher ADOS scores (more autistic characteristics) were associated with poorer imitation success [OR = .93; $p = .01$], but the effect of SCQ did not reach statistical significance [$p = .62$]. These findings follow Dziuk et al. (2007) that imitation performance predicted ADOS scores.

Discussion

Imitation Performance Across Tasks

The results of this study support previous findings suggesting that there is a pervasive imitation deficit in individuals with ASD. The individuals with autism demonstrated deficits in the imitation of meaningful gestures across all three tasks. Not all tasks were performed equally; a pattern emerged in both the ASD and TD groups, which revealed that pantomime imitation was performed *worse* than imitation of transitive gestures, with intransitive gestures having the highest rate of success. This pattern is identical to the one reported in a population of healthy adults (Mozaz et al. 2002; Carmo and Rumiati 2009).

Recognition Performance Across Tasks

Similarly, all three gesture *recognition* tasks were performed significantly worse by the ASD group than by the TD group. Contrary to the imitation results, intransitive gesture recognition was shown to be the most difficult task, followed by pantomime and object recognition. Interestingly, the same overall pattern of imitation and recognition performance across tasks was observed in the TD group, suggesting that even in typically developing populations, the performance of imitation tasks may vary depending on the tested gesture type.

Moreover, both groups performed recognition of intransitive gestures more poorly than the recognition of pantomimes. One reason for this pattern could be that it was an adult who chose the intransitive gestures to be included in the task, involuntarily creating a bias in the attribution of children's communicative gestures. Another reason could be that the ability to recognize communicative gestures may develop at a different rate than object related actions, as suggested by the results achieved in healthy adults (Bartolo 2002; Mozaz et al. 2002).

Effects of Cognitive Variables on Performance

Group differences in imitation and recognition were re-examined after the cognitive variables were statistically controlled for in the regression models. Within both groups, better performance on working memory and visual perception tasks were associated with *increased* imitation success, while higher digit recall scores were associated with *lower* imitation success. Past research has found a relationship between working memory and pantomime imitation (Bartolo et al. 2003). In particular, the authors suggested that to successfully execute pantomimes the role of working memory is necessary to maintain on line the semantic information stored in the long-term representations. The authors concluded that, as a consequence, a selective deficit in working memory abilities would thereby contribute to a selective deficit in pantomime production (Bartolo et al. 2003). However, in the current study, group differences could not be accounted for by age, IQ, or performance on cognitive variables such as visual motor or working memory abilities since group difference in imitation and recognition of gestures remained after the cognitive variables were controlled.

Error Types

To better understand the reasons behind the imitative failures in ASD, the specific error types contributing to the imitation failures were examined. Although the individuals with autism made more errors, the error rate was calculated as the percent of gestures with specific error types among all gestures with errors. After comparing the error rates in both groups, it was determined that the rates differed depending on the imitation task. One specific type of error in the ASD group was considered of particular importance because *hand configuration* errors have been reported to be the most frequent error type in patients with limb apraxia (Buxbaum et al. 2005). The hand error rate statistically differed between the two groups and this finding extended to transitive gestures and pantomimes, both object-related gestures. The results showed that in the task pantomime imitation there was a main effect of *hand* and *reversal* errors, whereas in intransitive gesture imitation only *amplitude* error rates significantly differed between the two groups. In transitive gesture imitation, *hand* error rates significantly differed between the two groups. These findings are in line with previous studies reporting that individuals with ASD and developmental dyspraxia demonstrate more spatial errors than errors in other categories (e.g., body part as object, temporal, and content: Mostofsky et al. 2006).

Williams et al. (2001) also predicted various error patterns including the presence of reversal errors in individuals with autism, as further support for the MNS theory. These current findings revealed that the error rates of reversal errors differed significantly between the groups in pantomime imitation but not for transitive or intransitive gesture imitation, partially supporting the theory. Another prediction of the MNS hypothesis was that individuals with autism would perform better in imitation of actions with objects, possibly as a result of object affordances. On the contrary, this current study identified *intransitive gestures* as being performed better than object related gestures thereby not supporting these predictions.

Association Between Recognition and Imitation

Further investigation of the recognition and imitation performance in ASD was undertaken using the theoretical explanations of mirror neurons and models of limb apraxia. The MNS theory suggests that a defective mirror neuron system underlies the imitation deficits so pervasive in individuals with autism (Williams et al. 2001) and addresses impairments in both gestural recognition[1] and imitation. The hypothesis predicts that the imitation deficits that are important to 'self and other' would be observed in

[1] One approach that has been used to test gesture recognition included a matching task requiring the participant to view a picture of a person making an action with the hand missing and choosing a picture of a hand in the best configuration to match the action (Hamilton et al. 2007; Rothi et al. 1991). Others, have measured gesture recognition by administering a task requiring participants to discriminate correctly from incorrectly executed gestures (Buxbaum et al. 2005; Cubelli et al. 2000).

individuals with autism; therefore it follows that deficits in both gestural recognition and imitation should be evident. The current findings revealed that the individuals with autism performed much more poorly than the TD in all tasks of gesture recognition and imitation. However, if the mirror neuron system holds gestural representations that are necessary for both recognition and imitation, then a correlation between the two should be identified. Indeed, these results revealed a correlation in the ASD group between pantomime recognition and pantomime imitation but not for intransitive gesture or transitive gesture imitation thereby only partly supporting the MNS hypothesis. Importantly, an association between pantomime recognition and pantomime imitation was not identified in the TD group.

Since the results did not fully support the MNS hypothesis, additional theoretical explanations were considered. The relationship between recognition and imitation has also been of interest in limb apraxia research. Even though cases have been identified showing a dissociation between pantomime recognition and imitation (Bartolo et al. 2003), a group study found a significant correlation between pantomime recognition and pantomime imitation (Buxbaum et al. 2005). Our results indicate that the error rates, correlations, and patterns of gestural processing were similar to those identified in limb apraxia patients. Therefore, perhaps a more parsimonious explanation of the pattern of recognition and imitation evidenced in the ASD group is grounded in theories of limb apraxia, specifically using a dual-route cognitive neuropsychological approach to gestural processing (Cubelli et al. 2000; Rothi et al. 1991).

Models of Limb Apraxia

According to this model, gestures are processed according to a lexical and a non-lexical route (Cubelli et al. 2000). It has been found that once a gesture is recognized as familiar it is reproduced using lexical route. If a gesture is not recognized as familiar, its reproduction will be carried out by a mechanism involved in the transformation of the visual information into motor acts using the non-lexical route (Bartolo et al. 2001). In this current study, the ASD group performed more poorly than the typically developing participants in their ability to recognize intransitive gestures, suggesting that intransitive actions are not generally well recognized by individuals with autism. In contrast, object related gestures (pantomimes and transitive gestures) were better recognized than intransitive actions, suggesting that they were processed using the long-term memory representation of the gesture along the lexical route. Given that TD group presented with the same pattern (better recognition of object related gestures than intransitive actions; and better imitation of intransitive gestures than object related gestures), the overall results indicate that the ability to imitate meaningful gestures might be explained using the cognitive model of gesture processing usually adopted for adults. Indeed, children appear to imitate gestures using the most developed cognitive route, as proposed by the dual-route model of limb apraxia (Cubelli et al. 2000, 2006; see Rumiati et al. 2009, for a recent review).

Performance of Pantomimes vs. Intransitive Gestures

The dual-route hypothesis can also account for the reversed results achieved in the recognition and imitation of gestures (intransitive gesture recognition being performed worse than the other gesture types while intransitive gesture imitation was performed the best). According to previous findings (Bartolo et al. 2001), since object related gestures were better recognized, they were presumably processed along the lexical route. Since intransitive gestures were not well-recognized in this study, they were presumably imitated along the non-lexical route. Given that the ASD group performed worse in all imitation tasks with respect to the TD group, both routes should be impaired. However, the ASD group performed significantly better in the imitation of intransitive gestures than object related gestures, suggesting that the non lexical route is better preserved than the lexical one (see also Cubelli et al. 2006). These findings suggest that the individuals with autism present with similar praxis patterns as observed in patients with limb apraxia and therefore cannot be fully accounted for by error patterns attributed to imitation impairments in line with the Mirror Neuron Theory account of imitation in autism.

Comparison to Previous Studies

To our knowledge, this is the first report of between group differences across *three* different types of gestures: transitive, intransitive, and pantomimes. Other studies have often collapsed intransitive gestures and pantomime imitation scores together for analysis and/or not included a test for transitive gesture (object use) imitation (Dewey et al. 2007; Mostofsky et al. 2006). Furthermore, an in-depth analysis of the error types along with tests measuring cognitive performance provided insight into the reasons behind the imitation deficits. Deficits in pantomime imitation (Bartolo et al. 2003), findings of hand posture errors including spatial errors (Mostofsky et al. 2006), and associations between pantomime imitation and recognition (Buxbaum et al. 2005; Rothi et al. 1991), have all been demonstrated in patients with limb apraxia. These same characteristics were observed in this sample of individuals with autism. Our findings differ from previous reports that individuals with autism do not present with gestural recognition deficits (Hamilton et al. 2007; Smith and Bryson 2007). There may be several explanations as to why significant impairments in gestural recognition in three separate tasks were identified. This current study tested three different gesture categories (transitive, intransitive gestures, and pantomimes) that included twenty trials each (for a total of sixty trials of recognition and sixty trials of imitation). Hamilton et al. (2007) tested recognition of nine pantomimes and nine symbolic gestures and Smith and Bryson tested recognition of six actions with objects and six communicative gestures. Moreover, the procedures varied across studies. Hamilton et al. (2007) used a matching approach and Smith and Bryson's (2007) procedure included miming the object and requesting the participant to verbalize a response.

Conclusions

The aim of the present work was to study the relationship between (transitive, intransitive and transitive) gesture recognition an imitation in two groups of children, one typically developing (TD) and one group characterised by individuals with autism spectrum (ASD). The relationship between gesture recognition and imitation in ASD could be interpreted along with the mirror neuron system theory. This theory predicts that the imitation deficits that are important to 'self and other' would be observed in individuals with autism; the mirror neuron system holds gestural representations that are necessary for both recognition (action observation and comprehension) and imitation, therefore a correlation between the two should be identified. However, recent studies on limb apraxia (acquired deficit of gesture processing) suggest that recognition and imitation of gestures might be processes along two different routes: if a gesture is recognised as familiar, a lexical route should be used, if the gesture is unfamiliar, it will be processed along a non-lexical route, therefore no relationship between gesture recognition and imitation should not be in relation.

Results revealed that in all tasks of recognition and imitation, the ASD group performed significantly worse than their TD comparison group. Intransitive gesture recognition was shown to be the most difficult task, followed by pantomime and object recognition and in tasks of imitation, pantomime imitation was performed *worse* than imitation of transitive gestures, with intransitive gestures having the highest rate of success. The same overall pattern of imitation and recognition performance across tasks was observed in the TD group. Importantly, significant correlations between recognition and imitation was not evident across all tasks, and the presence of reversal errors significantly differed only in the pantomime imitation task, thereby only partly supporting the Mirron Neuron Theory of imitation. The association between recognition and imitation was then addressed using a dual-route model of cognitive processing. Since intransitive gestures were more poorly recognized than the other gesture types, it was hypothesized that for their imitation they were processed along the non-lexical route. Furthermore, intransitive gesture imitation was performed better than object related tasks suggesting that two different routes of processing were used to imitate different gesture types. In sum, the cognitive processing of gesture imitation in autism is an important area of research, and the Mirror Neuron Theory of imitation cannot account for all of the patterns of praxis processing evident in individuals with autism.

Appendix 1: Stimuli Used for Imitation and Recognition Tasks

Stimuli for Gesture Imitation

Object Use: hairbrush (example: locker combination lock, computer mouse; bell, nailbrush; rolling pin; tape measure; calculator; instrument (recorder, hole punch; guitar pick; bottle; spatula; binocular; camera; remote control; ball; paper airplane; spoon; keyboard; baseball cap.

Pantomimes: camera (example): knife; wooden spoon; salt shaker; toothbrush; paper; rain hood; pitcher; bow and arrow; shovel; rope; peeler; weight; hat; key; headphones; book; snowball; yoyo; cup; key; soap.

Intransitive Gestures: peace sign (example); money; all done; too loud; look; listen; read; swatting a fly; crazy; stop; pay; choke; don't look; blow a kiss; throw a punch; let's go; roll the dice; hands up; you; cold; hot.

Stimuli for Gesture Recognition

Object Use: dialing phone (example) using a toothbrush as a screwdriver; paper airplane; putting on a hat that covers eyes; hairbrush; brushing hair with eye glasses; playing tennis with a hammer; scissors; brushing teeth with hairbrush; hammering with a screwdriver; spoon; cell phone; using PS2 control on the ear; keyboard; playing tennis with cell phone; remote control; brushing hair with drumstick; headphones; gameboy; playing guitar with tennis racket; ball.

Pantomimes: zipper (example); bringing a spoon to nose instead of mouth; ring; phone; opening can and pouring on head; camera; key; glass; dipping bubble wand and blowing bubbles away from wand; headphones; bringing cup to cheek; using a toothbrush to brush eye; yo-yo; peeling banana upside down; book; typing on a keyboard using incorrect orientation; snowball; writing with a pen with wrist turned; putting chapstick on forehead; backpack; dialing a phone and putting on head.

Intransitive Gestures: whisper (example); opening and closing hand; come here; be quiet; bringing two fists together; moving fingers up and down with palm backwards; angry; rotating fist; peace; side of hand on neck; sliding hand away from body; eat; index finger on ear; palm forward, fingers moving down; raising hand; round hand on neck; shucks; open; middle finger and thumb in circle; embarrassed; walk.

Appendix 2: Coding System for Imitation Tasks

Hand error: An error was recorded if the configuration of hand and fingers was not accurate or the wrist angle was incorrect. This code also encompassed hand grip; an error would be recorded, for example, if the (real or imaginary) object was held incorrectly.

Arm posture/trajectory error: This code encompassed errors of the arm. An error was recorded if the arm was at the wrong angle, if movement was in the incorrect plane (e.g., side to side instead of back and forth), or if the trajectory was inappropriate (e.g., circular instead of linear).

Amplitude error: An amplitude error was recorded if there was an error related to the size of the movement. For example, a movement was either too big or too small. (e.g., overshooting or undershooting a target).

Timing error: Timing errors were errors related to the speed or iteration of movement; for example, when the numbers of individual movements were inappropriate to the gesture (e.g., hammering only one time).

Reversal error: Copying a gesture in the perspective from which it was seen (e.g., palm facing the participant if that is the view observed).

Body part as object error: Use of a body part for the intended action (i.e., using their finger as a pen).

Distance error: Gesture performed at the incorrect distance from the target (e.g., shaking salt shaker at the level of the shoulder.

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