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Developmental dyspraxia is not limited to imitation in children with autism spectrum disorders

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Abstract

Impaired imitation of skilled gestures is commonly reported in autism. Questions, however, remain as to whether impaired imitation is associated with a more generalized deficit in performance of gestures consistent with a dyspraxia and whether the pattern of errors differs from that observed in typically developing children. To address these questions, praxis in 21 high-functioning children with autism spectrum disorders (ASD) was compared with 24 typically developing controls using a traditional approach in which performance was evaluated through detailed examination of error types. Children with ASD produced significantly fewer correct responses not only during Gesture to Imitation, but also during Gesture to Command and with Tool Use. The pattern of errors in ASD was similar to that of controls with spatial errors being most common in both groups; however, body-part-for-tool errors were more common in children with ASD, suggesting dyspraxia is not entirely attributable to motor deficits. The findings suggest that autism is associated with a generalized praxis deficit, rather than a deficit specific to imitation. In a developmental disorder such as autism, the findings may reflect abnormalities in frontal/parietal–subcortical circuits important for acquisition (i.e., learning) of sensory representations of movement and/or the motor sequence programs necessary to execute them. (*JINS*, 2006, *12*, 314–326.)

Keywords: Praxis, Apraxia, Motor skills, Imitation, Gesture, Asperger's

INTRODUCTION

Although autism has been historically characterized and defined by symptoms and signs of impaired socialization and communication, impairments in motor development are common, if not consistent, findings (DeMyer et al., 1972; Haas et al., 1996; Hallett et al., 1993; Jansiewicz et al., 2006; Jones & Prior, 1985; Rapin, 1991; Teitelbaum et al., 1998; Vilensky et al., 1981). Increased insight into the brain mechanisms underlying autism can be gained from careful consideration of these motor signs. By using tests of motor function for which the neurologic basis is well mapped out, it is possible to gain an understanding of the neural circuits impaired in autism; motor signs can also serve as markers for deficits in parallel brain systems important for control of the social and communication skill impairments that characterize autism (Williams et al., 2001).

One of the most consistent motor findings associated with autism is deficient performance of skilled motor gestures (DeMyer et al., 1981; Jones & Prior, 1985; Ohta, 1987; Rogers et al., 1996; Smith & Bryson, 1994). Impairments in imitation of skilled gestures have been particularly emphasized, with some investigators suggesting that impaired imitation may be a core deficit that contributes to abnormal development of empathy, shared ("joint") attention, and a sense of "other minds" (Rogers & Pennington, 1991; Williams et al., 2001).

Questions have been raised as to whether deficits in imitation reflect a more basic problem with motor execution/planning, visual processing, or sensory integration (Smith & Bryson, 1994; Green et al., 2002; Rogers et al., 2003), or whether they are the result of abnormalities in self–other mapping specific to imitation (Williams et al., 2004). Critical to addressing these questions is understanding whether impair-

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ments in gestural performance associated with autism occur only with imitation, or whether there is a more general impairment in performance of gestures. The issue remains unresolved. Some investigators have reported findings emphasizing a primary impairment in imitation (Rogers et al., 2003; Williams et al., 2004), others have documented impairments in performance of skilled motor gestures not only to imitation but also in response to verbal command or during actual tool use (DeMyer et al., 1972, 1981; Hammes & Langdell, 1981; Hertzig et al., 1989; Jones & Prior, 1985; Ohta, 1987; Rogers et al., 1996). Tasks examining performance of gestures to imitation and to verbal command are used to assess limb praxis in neurologically impaired adults (Gonzales Rothi et al., 1997; Heilman & Gonzalez Rothi, 2003), and findings of impairments in both have prompted several investigators to suggest that a dyspraxic deficit may be associated with autism (DeMyer et al., 1972, 1981; Jones & Prior, 1985; Ohta, 1987; Rogers et al., 1996).

The term "dyspraxia" was borrowed from adult neurology/neuropsychology disciplines where it (a less severe form of "apraxia") has been used to describe adults with acquired brain lesions resulting in impaired ability to perform skilled motor tasks. In this traditional context, different types of adult apraxia have been identified: limb-kinetic, ideomotor, ideational, and more complex forms. The best studied has been ideomotor apraxia, which is characterized by impaired ability to carry out skilled motor actions that is not secondary to abnormal motor dexterity and sensory function in the affected limb (Heilman & Gonzalez Rothi, 2003).

In contrast to the adult literature, there has been much more confusion over the use of the term "dyspraxia" in the literature on developmental motor problems in children (Zoia et al., 2002). Some authors have used the term to refer to any type of motor deficit not due to an identifiable neurologic disorder (Gubbay, 1975) and to clumsiness seen in children with learning disabilities consistent with developmental coordination disorder (DCD). Other investigators, however, have recognized the importance of using developmental dyspraxia to refer strictly to impairments in gestural performance not secondary to primary motor/sensory deficit, thereby defining it in a manner consistent with that of ideomotor apraxia (Cermak, 1985; Zoia et al., 2002). It has generally been defined as such in the autism literature (Rogers et al., 1996, 2003), although the approach to assessing praxis and the interpretation of findings have varied and have not always been consistent with the approach taken in the traditional studies of praxis.

After finding impairments reflecting widespread deficits in performance of gestures to both imitation and to verbal command in high-functioning adolescents with autism spectrum disorders (ASD), Rogers and colleagues (1996) suggested that there might be a "generalized dyspraxia" in autism, defining it in a manner in keeping with ideomotor apraxia. However, in a subsequent study with much younger children (Rogers et al., 2003), the same group found toddlers with ASD to be impaired in imitation but failed to find differences between those with ASD and typically developing controls on tests of "praxis." The praxis battery used in the toddlers was limited to performing novel actions with actual objects (e.g., removing a Nerf ball from a fish bowl or climbing out of a cardboard box) and did not incorporate more classic tests of praxis, such as pantomimed use of imagined tools, which is difficult to administer to toddlers. Consequently, the findings may exclude only difficulty with motor planning/execution and not with abilities to acquire (learn), store, recall, or transcode spatiotemporal representations of complex movements, which are critical to praxis (Heilman & Gonzalez Rothi, 2003).

To determine whether children with ASD display a general impairment in performance of gestures rather than just an imitation deficit, it would be useful to assess praxis in a comprehensive manner using a traditional approach in which performance of skilled motor gestures to command, to imitation, and with actual tool use are examined (Gonzales Rothi et al., 1997; Heilman & Gonzalez Rothi, 2003). Further, as has been done in examination of adults with acquired apraxia, it would be informative to move beyond simply determining whether these movements are performed correctly, also examining for the presence of specific error types: content, spatial, temporal, and concretization errors (Gonzales Rothi et al., 1997; Hanna-Pladdy et al., 2001a; 2001b; Heilman & Gonzalez Rothi, 2003; Poizner et al., 1995). Using these praxis evaluation procedures, studies of adults with brain lesions have provided important clues into the modular organization and neurological basis of acquired ideomotor apraxia/dyspraxia (referred to in this paper simply as "apraxia"; Clark et al., 1994; De Renzi et al., 1980; Hanna-Pladdy et al., 2001a, 2001b). Analysis of errors have revealed that spatial errors are the most common type observed in ideomotor apraxia, and lesion-based analyses reveal that the left parietal lobe appears to be important for storing spatiotemporal and conceptual representations of skilled movements, whereas specific components of action programs such as external configuration (object orientation) and speed of movement appear to have bilateral representations (Hanna-Pladdy et al., 2001b).

In contrast, the neurologic basis of so-called "developmental dyspraxia," including that reported to be associated with autism, remains unclear. This may, in part, be due to the inconsistent use of the term (Denckla & Roeltgen, 1992) but also reflects failure to apply a traditional adult neurological approach to analysis of the praxis error types on tasks involving gesture to command, gesture to imitation, and tool use in children with ASD. This traditional neurologic approach, however, has been applied to examination of other childhood populations, including typically developing children and those with DCD (Hill, 1998; Zoia et al., 2002). Zoia and colleagues (2002) found typically developing children, ages 5–10 years, show a progressive maturational pattern, with Gesture to Imitation and Tool Use ("visual plus tactile") maturing before Gesture to Command ("verbal"). The findings in children with DCD suggest a general maturational delay, with age-related impairments across all

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modalities (Cermak et al., 1980; Dewey & Kaplan, 1992; Hill, 1998; Zoia et al., 2002). Error analysis of praxis has also been used to examine children with developmental motor deficits (Dewey, 1993). These children showed increased "action" and "movement" errors, consistent with the types of errors made by adults with acquired ideomotor apraxia. We are unaware of any published literature focused on analysis of praxis error types in autism. Such an approach could provide insight into the neurologic basis of motor deficits associated with autism, which could strengthen our understanding the biological basis of the disorder.

Given these observations, we sought to evaluate the praxis error patterns in children with ASD using the traditional examination approach that has been useful in the assessment of adult-onset acquired apraxia and in children with DCD. Using this approach, our first goal was to determine whether the deficits in performance of skilled motor gestures in children with ASD are specific to Gesture to Imitation or whether they also include Gesture to Command and with Tool Use. We hypothesized that children with ASD would show impairments on praxis examination compared with healthy gender- and age-matched controls and that they would show impairments not only on Gesture to Imitation but also with Gesture to Command and with Tool Use, thereby reflecting impairment consistent with a generalized dyspraxia.

We also sought to determine whether the pattern of dyspraxic errors in children with ASD differed from that seen in typically developing children. Children with ASD have been found to show difficulty perceiving spatial relationships, including those associated with body position, and we hypothesized that spatial errors would be a primary contributor to poor performance on praxis examination. Churchill (1972, 1978) showed that children with ASD had difficulty understanding prepositions involving spatial relationships, whereas Wing (1969) found that children with ASD show difficulty with spatial orientation (up–down, front–back, left–right). In a study of imitation (Ohta, 1987), investigators found that children with ASD tend to exhibit "partial imitation." The investigators posited that partial imitation is related to viewing the examiner's body parts (hands, arms) as being separate from the rest of the body and that children with ASD have difficulty perceiving that parts are related/connected as a whole in their mental images (often referred to as simultanagnosia). They further speculated that impaired gestural imitation in children with ASD reflects a disorder in "mental image, especially body image." We, therefore, hypothesized that spatial errors would be the most frequent error made by children with ASD and would make the largest contribution to increased errors in these children relative to controls.

A further aim was to examine associations of praxis with age in children with ASD relative to controls. Dyspraxia in other child populations, such as DCD, suggest a general maturational delay (Dewey & Kaplan, 1992; Hill, 1998; Zoia et al., 2002), and we hypothesized a similar profile would be observed in children with ASD.

Lastly, the children with ASD included in this study met criteria for either high-functioning autism (HFA) or Asperger's syndrome, and we also sought to compare performance between children with HFA and those with Asperger's syndrome. Prior studies show that these two groups of children perform similarly on tests of fine and gross motor ability and coordination (Ghaziuddin & Butler, 1998; Jansiewicz et al., 2006; Manjiviona & Prior, 1995), and we hypothesized that children with HFA and Asperger's syndrome would perform similarly on praxis examination.

METHODS

Participants

A total of 45 male children between the ages of 8 and 12 years old participated in the study: 21 were diagnosed with an ASD, HFA, or Asperger's syndrome; 24 were gender- and age-matched controls with no neurologic or psychiatric disorders. Student's *t* tests were performed to examine whether there were differences in age between groups. The results are presented in Table 1.

Subjects were recruited from several sources, including outpatient clinics at Kennedy Krieger Institute, through advertisements placed with community-wide service groups, volunteer organizations, local schools, and medical institutions, as well as by "word of mouth." Of the children with ASD, 13 were diagnosed with HFA, whereas 8 were diagnosed with Asperger's syndrome. HFA/Asperger's syndrome diagnoses were based on the Autism Diagnostic Interview–Revised (ADI–R; Lord et al., 1994) and Autism Diagnostic Observation Schedule–Generic (ADOS–G; Lord et al., 2000) and the earlier edition of the ADOS (Lord et al., 1989). Participants with ASD were classified as HFA or Asperger's syndrome, based on their early language history from the ADI (Lord et al., 1994) using methodology described by Szatmari and colleagues (1995) in published

Table 1. Subject demographics

	Controls, $n = 24$	Autism spectrum disorder (ASD), $n = 21$*	*p* value
Age Mean (*SD*)	10.68 (1.61)	10.6 (1.98)	$p = 0.87$
FSIQ Mean (*SD*)	118.3 (11.8)	99.68 (15.23)	$p = 0.0001$
PSIQ Mean (*SD*)	113.2 (13.45)	98.98 (13.59)	$p = 0.0019$
VSIQ Mean (*SD*)	120.31 (11.17)	99.11 (19.86)	$p = 0.0001$

*The autism spectrum disorders (ASD) group includes 13 boys with high-functioning autism [HFA; mean (*SD*) age, 10.4(1.9); Full-Scale IQ (FSIQ), 93(12); Performance IQ (PIQ), 95(10); Verbal IQ (VIQ), 93(12)] and 8 boys with Asperger's syndrome [mean (*SD*) age, 10.8(2.2); FSIQ, 108(17); PIQ, 105(18); VIQ, 108(16)].

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examinations of behavioral/cognitive distinctions between autism and Asperger's syndrome. All children in the ASD group demonstrated impairments in reciprocal social interaction, abnormalities in verbal and nonverbal communication, and repetitive and/or stereotyped behavior. Children with HFA not only met ADI algorithm criteria for autism but also had histories of development of spontaneous speech after 36 months of age or some evidence of deviant language development such as delayed echolalia, pronoun reversal, or neologisms. Children with Asperger's syndrome spoke in phrases by 36 months of age and showed no deviant language development. Children with diagnoses of conduct disorder, mood disorders, and anxiety disorders (other than simple phobia) were excluded from the study.

The Diagnostic Interview for Children and Adolescents-IV (DICA-IV) was used to determine the presence of additional psychiatric diagnoses in both ASD and control children. Control children with any diagnosis on the DICA-IV or with any immediate family members (siblings, parent) with ASD were excluded from the study. All control subjects had no histories of seizures or evidence of any other neurological disorder. Based on the DICA-IV, within the ASD group, six had a secondary diagnosis of attention deficit–hyperactivity disorder, two obsessive–compulsive disorder, two simple phobia, and one oppositional defiant disorder. Eight (38%) of the children with ASD were on psychoactive medications. No participants in the control group were taking any psychoactive medications. Of the children with ASD, eight were taking stimulants, one was taking selective serotonin reuptake inhibitors, one was taking alpha-adrenergic agonists (guanfecine or clonidine), one was taking an atypical neuroleptic (risperidone), and one was taking an antidepressant (buspirone). Stimulant medications were discontinued 24 hours before testing, but all other medications were taken as prescribed.

Intellectual level was assessed at the time of the study using the Wechsler Intelligence Scale for Children, 3rd Edition (WISC-III; Wechsler, 1991), except for one subject with ASD who received the Wechsler Intelligence Scale for Children, Revised (WISC-R; Wechsler, 1974); this subject's Full Scale IQ was adjusted using the previously published estimation equation for adjustment of WISC-R scores to a WISC-III equivalent (Cohen et al., 2002). All ASD and control subjects obtained WISC-III Full Scale IQs of 80 or above (see Table 1 for group means).

INVESTIGATIVE MEASURES

Praxis Testing

A version of the Florida Apraxia Screening Test (Revised; Gonzales Rothi et al., 1997) was used to examine whether subjects with ASD showed deficits in performance of skilled motor gestures. Several studies have used this apraxia battery to investigate apraxia and evaluate error patterns in adults with neurologic disorders, including Alzheimer's disease (Jacobs et al., 1999a; Pharr et al., 2001), corticobasilar degeneration (Jacobs et al., 1999b; Merians et al., 1999), and progressive supranuclear palsy (Pharr et al., 2001); the battery has not been applied previously to investigations of children with developmental disorders. For the current study, the examination was adapted for children; gestures likely to be unfamiliar to children (shaving, hitchhiking, using wire cutters) were eliminated while an item for tooth brushing was added. From a developmental perspective, the praxis examination included gestures learned during early childhood (e.g., waving goodbye), as well as those acquired later in childhood (e.g., using scissors).

Trained psychologists administered the praxis examination. The sections included Gestures to Command, Gestures to Imitation, and Gestures with Tool Use. Each section included 25, 25, and 17 commands, respectively. The children sat at a table opposite the examiner. Subjects were videotaped during the praxis examination for later scoring. Two independent raters who were kept blind to diagnosis evaluated each videotaped examination. The Gesture to Command section required that each subject pantomime 25 different skilled motor gestures. Seventeen of the gestures were transitive, requiring the imagined use of an object to complete the task; seven gestures were intransitive. Examples of transitive gestures include hammering a nail as if into a wall and using a pair of scissors as if cutting paper. Examples of intransitive gestures include waving goodbye and making a fist. Because handedness plays a role in gestures where content is clear (e.g., habitual use of right hand while combing) and subjects were not consistently asked to use the dominant hand for each gesture, switching hands for gestures in the Gesture to Command section was not considered incorrect. The Gesture to Imitation section included all of the 25 gestures from the Gesture to Command section. The subjects were free to choose which hand would perform the imitation of each gesture. In the Gesture with Tool Use section, a tool was placed midline in front of the child, who was asked to demonstrate its correct use while holding the tool. Gesture with Tool Use included the 17 transitive items from the Gesture to Command section.

Scoring

Each gesture within each section of the praxis test was scored as correct or incorrect. For incorrect gestures, the types of errors were classified based on those described by Gonzales Rothi et al. (1997). For the current study, the error categories included Spatial, Body-part-for-tool, Temporal, and Content/Concretization. It was possible for a gesture to be labeled as showing more than one type of error. The following is a concise description of error types based on descriptions from Gonzales Rothi et al. (1997):

Spatial errors suggest that the spatial representation of the gesture is incorrect. There are four types of spatial errors: internal configuration, external configuration, spatial movement, and amplitude. Internal configuration errors are described as incorrect positioning of the hand with relation to the tool, whereas external configuration errors occur when

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the body parts and imagined tool are not in a correct relationship with the object receiving the action. Incorrect joint coordination when activating the movement is labeled as a spatial movement error. An amplitude error is defined as any magnification, reduction, or/and irregularity of the amplitude of gesture. For the current study, all four of these error types were collapsed into a single "spatial error" group.

Body-part-for-tool errors refer to the use of hand, finger, or arm as the tool of gesture. An example of a Body-part-for-tool error is cutting with scissors by moving the index and middle fingers together and apart. Although categorized as a spatial error according to Gonzales Rothi et al. (1997), we chose to account for Body-part-for-tool errors separately due to their distinction from other types of spatial errors.

Temporal errors occur when the timing, sequence, and/or occurrence of the gesture is incorrect. Timing errors are those that alter the typical timing or speed of a pantomime.

Sequence errors involve any disruption of the sequence including the addition, deletion or transposition of movement elements.

Occurrence errors refer to gestures that multiply characteristically single cycles or decrease a repetitive cycle to a single occurrence.

Content/Concretization errors, where *Content errors* indicate that the content of the gesture is incorrect. These errors can be further characterized as perseverative, related gesture, nonrelated gesture, and hand gesture. Perseverative errors occur when the patient produces a response that includes all or part of a previous gesture. In a related error, the content is related to the correct gesture, whereas a nonrelated gesture is accurately produced, but unrelated to the correct gesture. An example of a related gesture is playing the violin instead of the flute. A "hand" content error occurs when the patient uses the hand instead of the correct imagined tool to perform the gesture. For example, the subject may pretend to rip a piece of paper when asked to pantomime cutting paper with scissors. Similar to a hand content error, a *Concretization error* occurs when the transitive pantomime acts on a real object not normally used in the task rather than on a relevant imagined object. Due to the similar nature of content and concretization errors, these errors were collapsed into a single "content/concretization" group.

Responses were categorized as *Unrecognizable/No Response* when the participant either did not respond to a particular command or the response made was not identifiable as any particular gesture, related or non-related.

STATISTICAL METHODS

Inter-rater Reliability

The Bland Altman method (Bland & Altman, 1986), Intraclass Correlation Coefficient (ICC), and Pearson's correlation were used to assess agreement between two independent observers. Reliability was assessed for both total percent correct scores and total absolute errors calculated for overall assessment of praxis examination and also for designated error type (spatial, body-part-for-tool, temporal, and content/concretization) for each incorrect response. Conducted to evaluate reliability across the entire range of overall scores, the Bland Altman method involved computation of mean difference between measures (d) and the 95% confidence interval (CI) of $\bar{d}$. Results demonstrated good inter-rater agreement between two raters for both total percent correct and total absolute errors. The mean difference between two raters was small and randomly distributed close to the line of zero bias across the range of scores for both total percent correct ($\bar{d} = 2.7$; 95% CI = −0.5 to 5.9) and total absolute errors ($\bar{d} = -1.6$, 95% CI = −1.1 to 4.3). For total percent correct and total absolute errors, respectively, ICCs were .85 and .92 and Pearson's correlation coefficients were .86 and 0.93, all p's $< .001$.

Regarding Error Types, the reliability was high between raters for total spatial errors, (ICC = .86, $r = .87$, $p < .0001$), body-part-for-tool errors (ICC = .85, $r = .88$, $p < .0001$), and unrecognizable/no response (ICC = .87, $r = .90$, $p < .0001$). There was moderately high reliability for content/concretization errors (ICC = .77, $r = .79$, $p < .0001$). The reliability for temporal errors was relatively low between raters ($r = .34$, $p = .02$); scorer 2 overscored relative to scorer 1. There was no difference, however, in reliability based upon group (i.e., when considering reliability within ASD alone or controls alone). For the purpose of this study, we have removed temporal errors from the rest of the analyses and used averages of the two scorers for comparison of the remaining scores.

Comparison of Performance on Praxis Examination Between ASD and Controls

The indices used to evaluate performance on praxis examination were as follows:

Overall performance was assessed using total number of errors made and total percent correct responses.

Section-wise performance scores were generated as percent correct responses on each of the three sections, namely, Gesture to Command, Gesture to Imitation, Gesture with Tool Use.

Error types were defined in terms of the percent contribution of a particular error type to total errors made, after adjusting for error opportunities. Error opportunities took into account the total number of different types of spatial (i.e., 4), Body-part-for-tool (i.e., 1), or content/concretization (i.e., 5) errors (i.e., that, for each gesture. there is opportunity for four different spatial errors, but only one body-part-for-tool error, thus percent contribution of spatial errors to total errors may appear larger than percent contribution of body-part-for-tool errors to total errors, simply because of greater opportunity of making spatial errors). Error opportunities accounted for total number of possibilities for making a specific error type on a command, and all absolute errors scores were divided by the respective error opportunities to generate opportunity-adjusted error scores, thus

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are weighted according to the number of chances for making the error. These adjusted error type scores were then used for computing percent contribution of particular error type to total errors [(number of a particular error type/total number of errors) × 100]. However, when comparing absolute number of the same error type between groups (for instance, total number of spatial errors in ASD *vs.* total number of spatial errors in Control), this adjustment is not required because both groups are presented with the same opportunity of error.

Statistical comparison of the above-defined indices for performance on praxis examination was done using robust, non-parametric, minimum absolute deviation, median regression, adjusting for age and Full-Scale IQ. Adjustment for age and IQ was done due to significant association between age and total errors on praxis examination ($r = -0.34$, $p = .02$), and also between IQ and total errors on praxis examination ($r = -0.64$; $p < .001$). Nonparametric median regression is a type of quantile regression minimizing the sum of absolute deviations about the median (Koenker & Bassett, 1978). It was used to account for potential distortions due to large outliers in a relatively small sample size. All results are reported as predicted medians from the above median regression models (age- and IQ-adjusted median and 95% CI of the adjusted median). The nonparametric matched pair sign test was used to assess the difference in performances on the sections of praxis examination.

Evaluation of Association Between Age and Performance on Praxis Examination

Pearson's correlation coefficient was used to assess association of age with performance on praxis examination. Bootstrap re-sampling (Efron & Tibshirani, 1993) with 50 repetitions was used to assess the difference between correlation coefficients using a Z test on the difference between correlations.

Comparison of HFA and Asperger's Syndrome Subgroups on Praxis Examination

Nonparametric Kruskal–Wallis test was used to evaluate the difference in performance on praxis examination between HFA and Asperger's syndrome groups. All statistical analyses were done using statistical software package STATA version 8.0 (STATA corporation, Austin, TX.).

RESULTS

Comparison of ASD and Control Groups on Praxis Examination

Table 2 provides detailed results from comparisons of the ASD and control groups on the praxis examination. All results are provided as age- and IQ-adjusted medians (95% CIs). Children with ASD made significantly more total errors on the praxis examination than did controls. The total errors in the ASD group ranged from 25 to 91, whereas in controls the total errors ranged from 10 to 50. Children with ASD also had fewer total percent correct responses compared to controls. The total percent correct response in controls ranged from 46% to 87% compared with 14% to 75% in the ASD group.

Furthermore, examination of section-wise performance revealed that children with ASD made significantly more errors on all three sections of the praxis exam (Gesture to Command, Gesture to Imitation, and Gesture with Tool Use). These results are graphically displayed in Figure 1. Figure 1 also shows that percent correct response on Gesture to Command section was significantly lower than on Gesture to Imitation and Tool Use in both controls and ASD (for controls: $p = .03$ and $p < .0001$; for ASD: $p = .004$ and $p = .006$, respectively); there was no significant difference between performance on Gesture to Imitation and Tool Use in both groups (Figure 1).

As shown in Table 2, the ASD group demonstrated significantly more spatial, content/concretization, and body-part-for-tool errors than did controls. Further comparison of these error types in the three sections of the praxis examination revealed that the ASD patients made significantly more spatial errors on Gesture to Command and Gesture to Imitation sections but not on the Tool Use section. Significant differences for content/concretization errors were present in the Gesture to Command section, with no significant differences for the Tool Use and Gesture to Imitation sections, primarily because subjects are less likely to make content or concretization errors when imitating a correctly performed gesture. For the same reason, body-part-for-tool errors were significantly higher only in the Gesture to Command section. By definition, no body-part-for-tool errors were made on the Tool Use section.

Analyses of distribution of error types after controlling for opportunity for error type revealed comparable proportional distributions of error types for both groups for all error types (see Figure 2). The spatial errors were the most frequently made type in both groups even after controlling for opportunity of errors. The ASD group demonstrated a relatively greater proportion of body-part-for-tool errors, compared to controls; however, the difference was not statistically significant after adjusting for age, IQ, and opportunity of error type. Table 2 presents results from these comparisons.

Evaluation of Association Between Age and Performance on Praxis Examination

Correlation between age and total errors was significant for children with ASD, $r = -0.55$, $p = .01$, but not for controls, $r = -0.34$, p = .09. Similarly, as shown in Figure 3, correlations between age and errors for each section of the praxis examination were significant for children with ASD (Gesture to Command: $r = .60$; $p = .004$, Gesture to Imitation: $r = .51$; $p = .02$ and Tool Use: $r = .57$; $p = .006$) but not controls (Gesture to Command: $r = .4$; $p = .05$, Gesture to

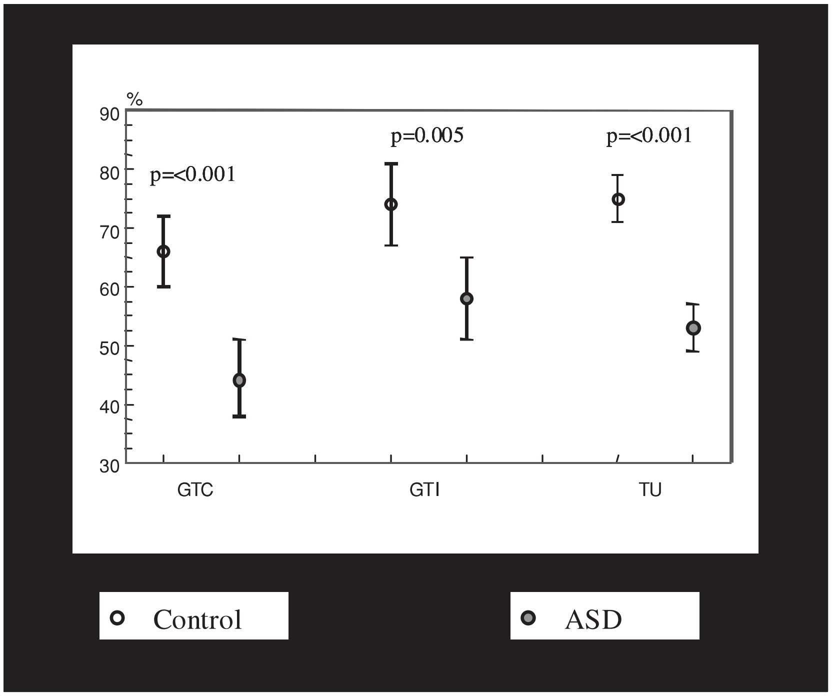

Fig. 1. Age- and Full-Scale IQ-adjusted medians (95% CIs), demonstrating significant differences in percent correct responses, to commands in all three sections of praxis examination between the control and autism spectrum disorder (ASD) groups. GTC, Gesture to Command; GTI, Gesture to Imitation; TU, Gesture to Tool Use Instruction; CI, confidence interval.

Imitation: $r = .23$; $p = .3$, and Tool Use: $r = .32$; $p = .12$). However, none of the differences of correlation coefficients between ASD and controls were statistically significant.

Comparison of HFA and Asperger's Syndrome Subgroups on Praxis Examination

There was a trend for lower Full-Scale IQ in children with HFA than with Asperger's syndrome (respective medians of 91 *vs.* 104, $p = .06$); however, the subgroup difference in Performance IQ was nonsignificant ($p = .3$).

There was no significant difference in average total number of errors or total percent correct responses between the two subgroups ($p > .3$), nor did the percent correct on each section of the praxis examination prove to be significantly different between subgroups (Gesture to Command: $p = .7$; Gesture to Imitation: $p = .6$; Tool Use: $p = .6$). There were a significantly greater number of body-part-for-tool errors in the HFA subgroup compared with Asperger's syndrome subgroup (respective medians of 4 and 1.25, $p = .02$). Sim-

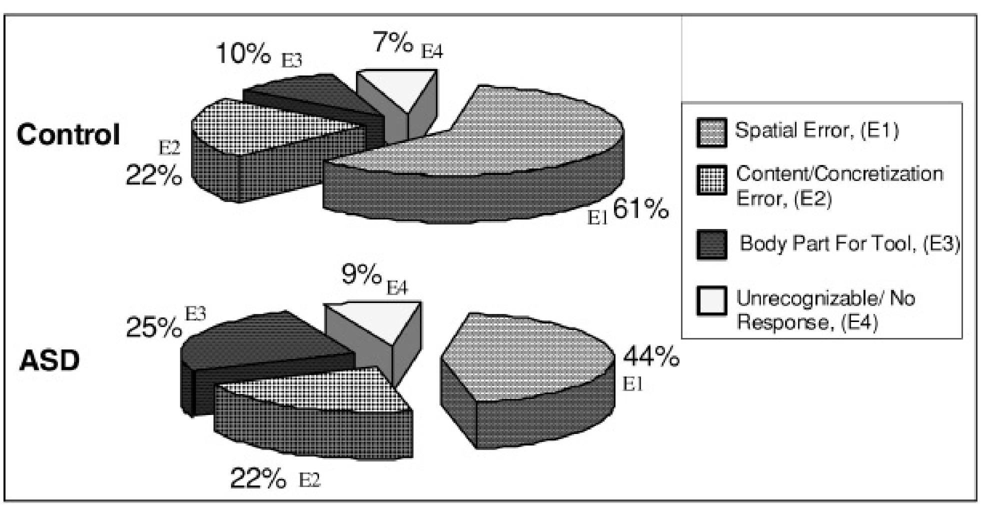

Fig. 2. Pie chart demonstrating the average percent distribution of error types in the autism spectrum disorder (ASD) and control groups. The proportions represented here are adjusted for opportunity of individual error types possible on the testing instrument. The ASD group has two main contributors to overall errors, body-part-for-tool (BPT) and spatial errors, whereas for the control group, spatial errors alone were the primary contributor to overall errors.

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Table 2. Comparative age and Full-Scale IQ (FSIQ)-adjusted medians (95% CIs) for the autism spectrum disorder (ASD) and control groups on the praxis examination

Variable	ASD Age and FSIQ-adjusted median (95% CI of adjusted median)	Control Age and FSIQ-adjusted median (95% CI of adjusted median)	*p* value
Overall performance			
a. Total errors made	51.4 (39.9 to 62.9)	27.2 (16.5 to 37.8)	.009
GTC	25.3 (19.8 to 30.7)	11.5 (6.6 to 16.5)	.002
GTI	16.5 (11.1 to 21.9)	7.4 (2.5 to 12.3)	.03
TU	7.8 (6.7 to 8.9)	4.9 (4.0 to 5.9)	.002
b. Total % correct responses	51.3 (42.1 to 60.4)	70.5 (62.3 to 78.8)	.008
GTC	44.2 (37.6 to 50.7)	65.7 (59.8 to 71.6)	<.001
GTI	57.8 (50.7 to 65.1)	74.1 (67.1 to 81.2)	.005
TU	52.8 (48.6 to 57.1)	75.5 (71.5 to 79.4)	<.001
Error types			
a. Total spatial errors	32.8 (25.4 to 40.2)	21.1 (14.5 to 27.7)	.04
GTC	13.1 (10.4 to 15.8)	7.0 (4.5 to 9.5)	.005
GTI	15.5 (11.9 to 19.1)	7.4 (3.9 to 10.8)	.005
TU	5.9 (4.4 to 7.5)	4.1 (2.7 to 5.3)	.11
b. Total BPT errors	2.8 (2.0 to 3.6)	1.0 (0.3 to 1.7)	.006
GTC	2.1 (1.5 to 2.6)	0.8 (0.3 to 1.3)	.006
GTI	0.5 (0.0 to 1.5)	0.0 (0 to 0.5)	.4
TU	NA	NA	NA
c. Total Content/concretization errors	7.5 (5.9 to 9.2)	1.8 (0.3 to 3.3)	<.001
GTC	7.2 (6.2 to 8.2)	1.6 (0.7 to 2.5)	<.001
GTI	0.0 (0.0 to 0.2)	0.0 (0.0 to 0.1)	1
TU	0.0 (0.0 to 0.3)	0.0 (0.0 to 0.2)	1
d. Total unrecognizable or no response	3.3 (2.3 to 4.4)	2.0 (1.0 to 3.0)	.11
GTC	2.2 (1.5 to 2.9)	1.3 (0.7 to 1.9)	.10
GTI	0.0 (0.0 to 0.4)	0.0 (0.0 to 0.2)	1
TU	1.6 (1.2 to 1.9)	0.5 (0.2 to 0.8)	<.001
Proportional distribution of errors (% contribution of each error type to total errors after adjusting for opportunity of errors)			
a. Percent spatial errors	39.8 (23.5 to 53.2)	53.8 (42.1 to 65.4)	.17
b. Percent BPT errors	19.8 (8.6 to 30.9)	11.4 (2.1 to 20.6)	.3
c. Percent Content/concretization errors	27.4 (14.2 to 40.6)	18.4 (7.6 to 29.2)	.4
d. Percent unrecognizable or No response	6.9 (2.7 to 11.0)	7.9 (4.2 to 11.7)	.7

Note. GTC = Gesture to Command; GTI = Gesture to Imitation; TU = Gesture to Tool Use Instruction; BPT = Body-part-for-tool; NA, not applicable; CI = confidence interval.

ilarly, the comparison of distribution of errors between HFA and Asperger's syndrome subgroups revealed a significantly greater proportion of body-part-for-tool errors in the HFA subgroup (respective medians of 29.3% and 11.6%, $p = .007$), after adjusting for opportunity of errors. Consequently, the spatial error proportion was lower in the HFA subgroup than in the Asperger's syndrome subgroup (respective medians 35.7% and 55.9%, $p = .04$). No significant differences existed between HFA and Asperger's syndrome in performance on all other components of the praxis examination.

DISCUSSION

The results indicate that high-functioning children with ASD show impairments on performance of gestures to command, gestures with imitation, and gestures with tool use. Regarding error type, children with ASD demonstrated significantly more spatial, body-part-for-tool, and content/concretization errors than did typically developing children matched in age. The distribution of error types in children with ASD was similar to that seen in controls, with the exception of body-part-for-tool errors, which were more frequent in the ASD group. Spatial errors were the most common type in both groups and, consistent with our hypothesis, made the largest contribution to increased errors in ASD in the Gesture to Command and Gesture to Imitation tasks. However, in the presence of the actual tool, the ASD group did not show significantly more spatial configuration errors than did controls.

Our findings of impaired ability to perform gestures to command and to imitation in high-functioning children with

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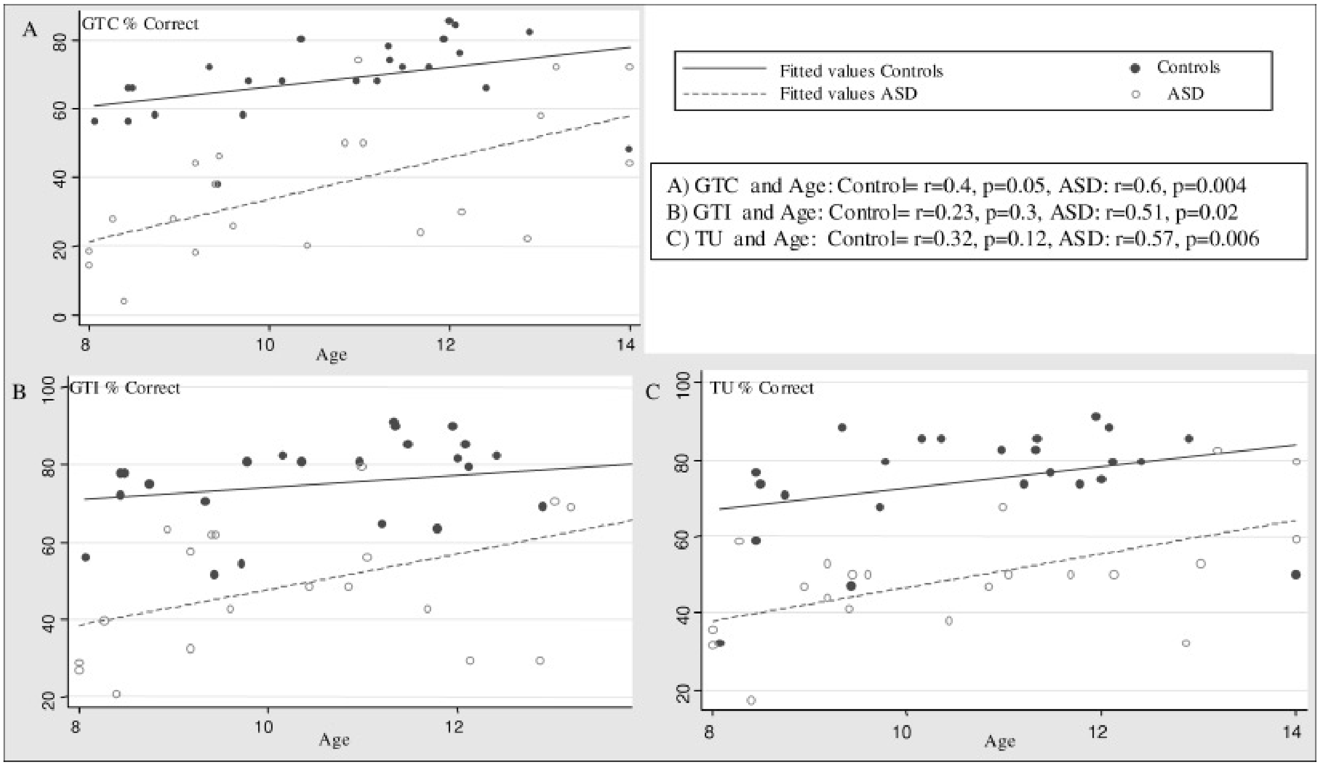

Fig. 3. Scatter Plot demonstrating correlation between performance on Gesture to Command (GTC), Gesture to Imitation (GTI), and Tool Use (TU) sections of the praxis examination and age in autism spectrum disorder (ASD) and control groups.

ASD are consistent with those from a prior study of high-functioning adolescents with ASD (Rogers et al., 1996). The latter study, however, failed to find impairments in adolescents with ASD during tasks involving tool ("object") use; this was in large part because both adolescents with ASD and controls in that study performed at ceiling on that task. Furthermore, the scoring methodology used in the prior study differed from ours and was based on judgment of overall accuracy. Our approach, examining for specific error types, likely increased sensitivity to inaccuracies in movement and may have resulted in an improved ability to reveal ASD-associated impairments not only in performance of Gesture to Command and Gesture to Imitation, but also in Tool Use.

Nevertheless, both our findings and those of Rogers et al. (1996) suggest that impairments in performance of skilled gestures in individuals with ASD are not limited to imitation. Rather, the findings in children and adolescents with ASD are consistent with a more generalized impairment in praxis. In fact, children with ASD in our study showed a pattern of impairment similar to that seen in adults with acquired ideomotor apraxia (Heilman & Gonzalez Rothi, 2003): they had the greatest difficulty with performing gestures to command and improved performance with imitation and with tool use, while still showing impairments under all three conditions. The findings, therefore, suggest that impaired performance of skilled gestures in autism is unlikely secondary to processes specific to imitation (e.g., self–other mapping); rather, it is likely due to abnormalities in processes common to all three conditions, such as mapping the precise kinesthetic/spatial aspects of movement, for which posterior parietal regions are critical, and/or planning of goal directed actions, for which premotor circuits are critical.

Spatial errors were by far the most common error for both children with ASD and controls, and children with ASD exhibited a spatial error rate approximately twice that of controls on Gesture to Command and Gesture to Imitation. It may be that the design of the praxis examination is weighted toward detection of spatial errors. Alternatively, spatial errors may indeed be the most common type in this age group, the results suggesting that accurate spatial representation of movement is relatively late in developing. Further investigation of age-specific distribution of error types in larger samples of typically-developing children could provide information about stages of acquisition of learned gestures during the developmental process.

Although not previously applied to studies of ASD, assessment of the distribution of errors on praxis examination has been used to investigate developmental trends in acquisition of complex motor skills in children with DCD (Dewey, 1993). Although a different approach to error analysis was used in that study, the overall findings were similar to ours. Specifically, children with DCD were more impaired than their normal counterparts on limb and orofacial praxis, but they showed error patterns similar to those of younger normal children. In the current study, the distribution of error types in the ASD group closely matched that in the group of typically developing controls, the exception being body-part-for-tool errors. The latter errors may represent a developmental phenomenon, as they characterize typically developing children up until 7 years of age (Kaplan, 1983). Given that the distribution of error types in children with ASD was otherwise comparable to that of typically developing children, our findings suggest that with ASD acquisition of skilled movements is delayed, but not necessarily disordered. Stone et al. (1997) proposed a similar model, concluding that rather than a dysfunction of imitation ability, children with autism exhibit a developmental delay of imitation skills.

In the current study, both children with ASD and controls showed improvement in performance with age for gestures in all three modalities (in response to verbal command, with imitation, and with tool use), although the correlations with age were significant only for children with ASD. These findings for children with ASD are consistent with results from a study of younger (5 to 10 year old) typically developing children and children with DCD (Zoia et al., 2002). Our study population was limited to children ages 8–12 years, and it may be that, in ASD, there is delayed acquisition of skilled movements earlier in development with some "catching up" during late childhood. This explanation would be consistent with conclusions drawn from a metanalysis of studies examining gestural imitation in autism (Williams et al., 2004). Furthermore, Zoia and colleagues (2002) found that, before 8 years of age, children produce gestures in response to visual stimuli more readily than to verbal command. Our age-related findings, thereby, may suggest impaired early learning of gestures through visual input. A follow-up study with a wider age-range would be informative in testing this hypothesis. Additionally, longitudinal studies comparing age-related performance on the praxis examination may be more conclusive in elucidating whether children with ASD show a unique pattern of praxis errors compared to that seen in other types of developmental disorders.

In traditional adult models, the term apraxia is reserved for individuals who demonstrate impaired ability to perform skilled motor tasks *that is not secondary to abnormalities in motor dexterity*. In contradistinction, findings from typically developing children and those with DCD reveal impaired performance on praxis examination to be associated with deficits in motor coordination (Dewey, 1993), raising doubts about whether the term "dyspraxia" is appropriate in the developmental context; that is, whether the term has an independent meaning as applied to developmental findings. Children with ASD, including those that are high-functioning, also have been found to show deficits in basic aspects of motor execution (e.g., Jansiewicz et al., 2006). It is unclear whether dyspraxic errors made by children with ASD are attributable to these basic motor impairments or whether they represent a distinct conceptual impairment of gesture. Our finding of increased body-part-for-tool errors in ASD suggests some contribution of conceptual impairment of gesture, as these errors are unlikely to be the consequence of basic motor dysfunction (Denckla and Roeltgen, 1992). However, further study is necessary to directly examine the association between basic motor deficits and findings of impaired performance on praxis examination.

In developmental disorders such as autism, it may be that common neural mechanisms underlie impairments in basic aspects of motor coordination and in performance of skilled motor gestures. One possibility is that impaired motor coordination results in poor performance on praxis examination. Alternatively, rather than a direct cause-and-effect relationship, it may be that impairments in motor coordination and praxis are epiphenomena, with both deficits resulting from abnormal development within similar brain regions/circuits. Frontal–subcortical systems important in motor execution/coordination are also important in acquisition of motor skills, that is, motor skill learning (for review, see Doyon et al., 2003). From a developmental standpoint, it may be that deficits in performance of skilled motor gestures result from impaired *acquisition* of spatial representations of movement and/or the motor sequence programs necessary to execute them (Roy et al., 1990). In contrast to acquired ("adult") apraxia, in which lesions of parietal and/or frontal premotor regions results in impaired performance of previously acquired stored motor skills, developmental dyspraxia, including that observed in ASD, may instead be due to a neurologic anomaly that affects the acquisition (i.e., *learning)* of motor skills. This explanation would be consistent with previously published findings revealing deficits in motor (procedural) learning in children with autism (Mostofsky et al., 2000). Parietal and frontal regions important for storage and implementation of spatial representations of complex motor gestures, respectively, have also been found to be important for procedural motor learning (Daselaar et al., 2003; Doyon et al., 2003; Ghilardi et al., 2000; Grafton et al., 1998; Muller et al., 2002; Schendan et al., 2003), so that it is possible that dysfunction within these regions contributes to impaired acquisition of motor skills in ASD. Alternatively, subcortical regions, including the basal ganglia and cerebellum, are critical for motor learning (reviewed in Doyon et al., 2003). Cerebellar pathology is one of the more consistent findings on postmortem examination of individuals with ASD (Bailey et al., 1998; Bauman & Kemper, 1994; Fatemi et al., 2002; Ritvo et al., 1986; Williams et al., 1980) and dysfunction within subcortical regions might contribute to impaired acquisition of motor skills in children with ASD. Further investigation of correlations between performance on procedural learning tasks and performance on praxis examination in children with ASD will help to determine whether impaired acquisition contributes to their difficulty with skilled motor performance.

Praxis in Autism *Versus* Asperger's Syndrome

Our results revealed similar levels of impairment in performance of skilled motor gestures in HFA and Asperger's syndrome; the two groups made similar numbers of total errors on each section of the praxis examination. The findings are consistent with those from previous studies (Ghaziuddin & Butler, 1998; Jansiewicz et al., 2006; Manjiviona & Prior, 1995) in which HFA and Asperger's syndrome groups were found to have similar degrees of impairments in more basic aspects for motor execution and coordination. The distribution of error types in HFA and Asperger's syndrome groups was also comparable, with spatial errors being the most common. However, there was one notable distinction in that the group with HFA showed increased body-part-for-tool errors compared with those with Asperger's syndrome. These errors were relatively few in number in both groups, and, therefore, unlikely to account for the overall difficulty with performance of complex gestures in either group. This observation, nevertheless, may provide insight into neuroanatomic differences between HFA and Asperger's syndrome.

Recent functional magnetic resonance imaging findings associate activation in the right supramarginal gyrus (BA 40) with body-part-for-tool (referred to as "body part for object") gestures (Ohgami et al., 2004); and considering the importance of the homologous left supramarginal gyrus in language function, dysfunction in this region may contribute to distinctions between HFA and Asperger's syndrome. Performance on praxis examination has been associated with language development (Hill, 1998; Thal et al., 1991) and poorer language skills may colocalize with increased body-part-for-tool errors in children with HFA.

Limitations

In this study, we used a tool originally designed for praxis assessment in adults, which was modified to make it more appropriate to children. A measure of praxis standardized for children has not yet been developed. A standardized praxis evaluation tailored for children that can be subsequently extended to everyday clinical use would be helpful for future investigations.

As discussed above, while restricting the age range of our participants to 8–12 years provided a more homogenous group, it limited our ability to examine developmental effects on praxis in children with ASD and controls. Several investigators have shown a high degree of developmental maturation in gestural performance during this age range for typically developing children and for children with developmental motor disabilities (Dewey, 1993; Kaplan, 1968; Overton & Jackson, 1973; Zoia et al., 2002). At the same time, studies have shown large discrepancies in performance on the praxis examination in these children at all age ranges, including adolescence. Questions about differences in developmental changes in praxis between children with ASD and typically developing controls can be more comprehensively examined in studies with a wider age range, and even better, in studies involving longitudinal assessment of performance on the praxis examination.

Praxis assessment in the current study was also limited by the fact that we did not account for the contribution of experience on performance ability. Experience using tools and performing gestures is difficult to quantify. Nevertheless, it is important to recognize that such experience can affect performance on praxis examination, in particular during gestures to command and gestures with tool use. It is possible that the children with autism in this study had less opportunity to learn and practice intransitive and transitive (i.e., tool use) gestures. This aspect may be particularly true for intransitive gestures, such as waving good-bye, which are often used in social context. Alternatively, impaired abilities to imitate, learn, and execute these social gestures may themselves contribute to atypical development of social reciprocity and even theory of mind observed in children with ASD (Rogers & Pennington, 1991; Williams et al., 2001). Indeed, that the children with ASD participating in this study showed impaired gesture with imitation, which is less dependent on past experience, suggests that lack of experience alone is unlikely to account for our findings.

CONCLUSIONS

A traditional approach to examination of praxis revealed that high-functioning children with ASD show impaired performance of gestures not only with imitation, but also in response to verbal command and with tool use. The findings suggest that processes specific to imitation are unlikely to entirely account for impaired performance of skilled gestures in autism; it is more likely due to abnormalities in processes common to performance of gestures across different conditions, such as those involved in mapping of the precise spatial/kinesthetic aspects of movement and/or planning of those movements. Furthermore, the pattern of dyspraxic errors and effects of age on performance suggest delayed, rather than disordered, development of gestural skills; and increased body-part-for-tool errors in children with ASD suggests that dyspraxia in ASD is not entirely attributable to deficits in motor coordination. In adults with acquired apraxia, the pattern of findings would suggest posterior parietal and/or premotor lesions that results in loss of previously acquired skills. However, in a developmental disorder such as autism, the findings are more likely attributable to abnormalities in frontal/parietal–subcortical circuits important for *acquisition/learning* of sensory representations of movement and/or the motor sequence programs necessary to execute them.

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