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Do planning and visual integration difficulties underpin motor dysfunction in autism?: A kinematic study of young children with autism

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Abstract

This paper examines the upper-limb movement kinematics of young children (3-7 years) with high-functioning autism using a point-to-point movement paradigm. Consistent with prior findings in older children, a difference in movement preparation was found in the autism group (n = 11) relative to typically developing children. In contrast to typically developing children, the presence of a visual distractor in the movement task did not appear to impact on early movement planning or execution in children with autism, suggesting that this group were not considering all available environmental cues to modulate movement. The findings from this study are consistent with the possibility that autism is associated with a difficulty using visual information to prime alternative movements in a responsive way to environmental demands.

Key Words: Autism, Motor processes, Movement kinematics, Motor preparation, Visual integration

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Existing estimates suggest that at least 63% of children with an Autism Spectrum Disorder (ASD) aged 2 to 6 years present with a neurological motor impairment (Ming, Brimacombe, & Wagner, 2007), with fine and gross motor dysfunction consistently reported in the autism literature (Fournier, Hass, Naik, Lodha, & Cauraugh, 2010). Kinematic analysis of upper-limb movement has provided important insights into the clinical picture of motor disturbance in autism by offering reliable, quantitative depictions of upper-limb movement deficits (Glazebrook, Elliott, & Lyons, 2006; Mari, Castiello, Marks, Marraffa, & Prior, 2003; Rinehart, Bellgrove, Tonge, Brereton, Howells-Rankin, & Bradshaw, 2006a). Such studies are particularly important given the social-communicative implications of upper-limb motor dysfunction (Dewey, Cantell, & Crawford, 2007; Fuentes, Mostofsky, & Bastian, 2009). Timely detection and management of early presenting upper-limb motor features in autism is also important for planning effective intervention strategies, particularly in the pre-school period. This is highly relevant given evidence to suggest that earlier administration of interventions is associated with better outcomes (Harris & Handleman, 2000).

To date, kinematic analysis of simple upper-limb movements in older children and adolescents with autism has demonstrated a profile of relatively intact movement execution, with deficits identified in motor planning. In the literature, motor planning is operationalized as movement preparation time; the time taken to initiate movement (Rinehart, et al., 2006a). Movement execution has been defined by the temporal and spatial kinematic features of movement (Rinehart, et al., 2006a). In a serial choice reaction time task, Rinehart, Bradshaw, Brereton, and Tonge (2001) identified longer movement preparation time in the context of intact movement execution time in school-aged children (5.5-15.3 years) with autism. Subsequent assessment of temporal and kinematic variables of movement preparation and execution on a digitized tablet point-to-point task also showed motor planning deficits in a school-aged autism group (5.5-11.8 years; Rinehart, et al., 2006a). In this task, children were required to move between a start position at the bottom center of a horizontal digitizing tablet to a target either at the top left, or top right of the tablet in response to an illuminated light. Movement execution characteristics were described by the total movement time, and the ratio of time taken to reach peak velocity relative to the total movement time. The authors found no difference between the autism and control groups in movement execution measures; however, movement preparation times were longer in the autism group, suggesting a deficit in the planning phase of movement that did not impede temporal aspects of movement execution.

The motor planning difficulties reported in children and adolescents with autism have also been identified in adults with autism. In a study of rapid point-to-point aiming movements in adults with an ASD (85% autism), Glazebrook, Elliott, and Lyons (2006) recorded longer movement preparation times to targets. The consistent finding of motor planning deficits at different time points in development, in the absence of any longitudinal analysis, provides an indication that this deficit may be a factor that influences upper-limb movement throughout childhood and into adulthood in autism. In contrast to studies of children, however, increased temporal and spatial variability in movement execution was noted in the adult sample, including longer overall movement duration, lower peak velocity and acceleration, and increased variability in time to peak velocity and spatial characteristics of movement. This finding may indicate age related changes in motor function in individuals with autism.

The utilization of visual sensory input for motor planning and control may also be abnormal in ASD (Glazebrook, Gonzalez, Hansen, & Elliott, 2009). Using a reach, grasp, and place task (the Bar Game) where subjects were required to transfer rods to discs, Hughes (1996) found that children with autism failed to demonstrate an appropriately planned grip (comfortable underhand or overhand grip) before moving the rod, nor did they adapt their approach position in response to a series of uncomfortable trials. Hughes attributed the poorer planning performance in autism either to a more fundamental deficit in sequencing ability, a failure to predict movement, or impaired visual control of movement. A reduction in the use of visual information when planning and undertaking movement was also suggested to account for shorter movement durations in children with ASD with average and high IQs (60% autism; age=7.4-13.1 years) when performing a reach-to-grasp movement (Mari, Castiello, Marks, Marraffa, & Prior, 2003). This interpretation is further supported by the impaired performance of children with ASD (age=6-10 years) on a clinical assessment of visual-motor integration (Mayes, & Calhoun, 2007).

The extent to which individuals with autism consider extraneous visual information when planning and executing movements is unclear. The presence of a three-dimensional object distractor positioned near a target has been found to influence upper-limb motion in healthy adults, who demonstrated changes in the temporal and spatial kinematic features of a reach-to-grasp movement in the presence of a distractor (Kritikos, Bennett, Dunai, & Castiello, 2000; Tipper, Howard, & Jackson, 1997). Evidence from sequential motor tasks indicates that children with autism may be less responsive to visual information that is not directly relevant to the goal of the immediate movement. Using a reach, grasp and place paradigm, Fabbri-Destro, Cattaneo, Boria, and Rizzolatti (2009) examined multiple component movements in 12 children with high-functioning ASD (mean age=10 ± 2.3 years) by manipulating the final motor component in a series of actions. Findings revealed that while control participants adjusted the temporal characteristics of their execution of the early components of the sequence based on the size of the final placement container, children with autism made no changes to their execution of the reach and grasp components of the sequence irrespective of the container size. Based on these findings, Fabbri-Destro, et al. suggested that children with autism program sequential movements in independent steps, rather than as a cohesive pattern. Fabbri-Destro, et al.'s sample were primary school age, thus it is possible that the motor pattern these authors describe is part of a compensatory strategy the young people have developed over time to manage the difficulties they face with fine and gross motor functioning. Alternatively, autism may be associated with a core difficulty in programming movements in a coherent manner using available advanced visual information, resulting in a ‘piecemeal’ motor pattern. Examination of sequential movement tasks in very young children is needed to clarify these potential explanations, and may further support the latter proposition.

The aim of the present study was to investigate the motor planning and execution patterns of young children with autism using an upper-limb movement kinematic task. The task was based on that developed by Rinehart, et al. (2006a) and used a touch screen displaying a point-to-point movement task for which participants were required to use a stylus to move between two points. In contrast to Rinehart, et al.’s examination of movement in the horizontal plane, children were required to move in a vertical plane. This change was made in order to utilize more advanced touch screen technology for measuring movement kinematics. Consistent with Rinehart, et al.’s findings in older children, a motor profile of impaired movement preparation and intact movement execution was hypothesized.

The current protocol extended the methodology of Rinehart, et al. (2006a) by the addition of a visual distractor positioned near the target. Using an adaptation from Kritikos, et al. (2000), the influence of a visual distractor on point-to-point movement kinematics in autism was examined. Previous studies have indicated a deficit in the use of visual information for movement in autism (Glazebrook, et al., 2009), in addition to an inability to use advance information to adjust early movement execution (Fabbri-Destro, et al., 2009; Hughes, 1996). On this basis, it was hypothesized that in the presence of an endpoint visual distractor, children with autism would not make adjustments to movement planning or execution whereas controls would adjust their movement.

Methods

Participants

Thirteen children with autism were recruited through Autism Victoria and various early intervention and social playgroups. Participants were aged between 3-7 years (range = 3.6-7.8 years). Children with autism were matched as closely as possible to a group of 13 typically developing (TD) children on age, gender and performance IQ (PIQ). The decision to match participants based on PIQ rather than Full Scale IQ was made in line with the reasoning of Qiu, et al. (2010). PIQ was assessed using the age appropriate Wechsler scale (Wechsler Intelligence Scale for Children- 4th Edition or Wechsler Preschool and Primary Scale of Intelligence- 3rd Edition; Wechsler, 2002; Wechsler, 2004). All children had a Full Scale IQ and PIQ >70. Two children with autism were unable to complete the age-appropriate Wechsler scale due to poor compliance. For these children, a developmental quotient (DQ) was calculated on the basis of their performance on the Psychoeducational Profile-3rd Edition (PEP-3; Schopler, Lansing, Reichler, & Marcus, 2004). The PEP-3 was designed specifically for the developmental assessment of individuals with autism, with reduced attentional and language requirements relative to other tests of cognition. DQ was calculated by finding the average developmental age across all subtests, divided by the chronological age of the child and multiplied by 100 (as per Delmolino, 2006). DQ's obtained on the PEP-R (an earlier version of the PEP-3) have been found to be a strong predictor of IQ scores and provide a good estimation of IQ in individuals who are not appropriate for standardized IQ assessment (Delmolino, 2006). Overall DQ on the PEP-R has also been significantly associated with IQ score on the Leiter-R, a non-verbal test of intelligence in children with autism or a pervasive developmental disorder (Portoghese, et al. 2010). As a PIQ score was unable to be determined from DQ, the DQ was considered to be an appropriate estimate of PIQ. Three children (two autism, one TD) were unable to complete the movement kinematic task due to poor compliance, likely a result of their young age. These children were excluded from further analysis. There were no significant differences between the remaining participants (11 autism, 12 TD) on age, $F(1,21) = .35$, $p = .56$, or PIQ, $F(1,21) = 1.3$, $p = .27$. A significant difference in Full Scale IQ between groups was identified, $t(21) = 2.4$, $p = .03$ (see Table 1).

[Place Table 1 about here]

All participants with autism had been previously diagnosed by at least one professional with expertise in autism who was not associated with this project. Five children had been administered the Autism Diagnostic Observation Schedule (ADOS; Lord, et al., 2000) at the time of first diagnosis. All diagnoses were confirmed by the first author using DSM-IV-TR criteria (American Psychiatric Association, 2000). Exclusion criteria included a diagnosis of a comorbid seizure disorder, neurological condition, or genetic condition (e.g., Fragile X, Down syndrome). The Developmental Behaviour Checklist- Primary Carer Version (DBC-P; Einfeld & Tonge, 2002) with autism algorithm was used to screen for autism in the TD group. The DBC-P is a 96-item caregiver report designed to evaluate emotional and behavioral function within the previous six month period. Items relate to problem behaviors and emotional responses, and are marked as either 0 (*not true as far as I know)*, 1 (*somewhat or sometimes true)*, or 2 (*very true or often true)*. A 29-item autism algorithm has been developed to screen for symptoms of autism, with scores above 17 on the autism subscale indicating likely autism. No TD child achieved a score above the cutoff on the DBC-P autism algorithm.

Apparatus

Movement kinematics were recorded with a computerized touch screen task using custom made software programmed in C# using Microsoft Visual Studio. Stimuli were presented on a 17 inch LCD touch screen (MicroTouch 3M M170), connected to a HP Compaq 6910p laptop. The touch screen was located centrally on a surface in front of the participant, and viewed from approximately 45cm at an angle of approximately 2.5 degrees from vertical and 87.5 degrees from horizontal. The seated height of the participants was adjusted to ensure that the center of the touch screen was approximately at eye level. Participants used an electronic pen-shaped stylus with their dominant hand (defined as hand preferred for using a pencil). Aiming movements were measured from a circular start position at the bottom center of the screen, measuring 20mm in diameter. The contact of the stylus on the starting position initiated measurement of movements, which were sampled at 125Hz. On making contact with the start position with the stylus, an identical circular target immediately appeared at the top of the screen, either at the left, center or right position. Movement recording ceased when the stylus made contact with the outer edge of the target. An abstract visual colour display appeared on the screen following each trial in order to maintain the participant's attention to the screen while allowing the researcher to prepare the next trial. The researcher was able to view the path taken by the stylus on the screen on the laptop. If the stylus was lifted from the screen, this was recorded as an error and the same trial was re-administered without informing the participant. Errors were recorded.

Five possible combinations of starting position and target were generated. In the simple movement task, participants moved between the starting position and a target situated at either the (a) left or (b) right top corner of the touch screen. In the visual distractor task, participants moved between the starting position and a target that was situated at the center of the top edge of the touch screen. This target was presented either (c) alone, or flanked by an equivalent-sized white distractor circle positioned either 61mm to the (d) left or (e) right of the center target. See Figure 1 for a detailed example of touch screen configuration.

[place Figure 1 about here]

Each participant completed five movement trials towards each target type (a-e), totaling 25 trials. The order of presentation of trials was randomly generated. When a participant demonstrated poor compliance, a minimal data set comprising only the simple movement task was administered. Three participants from the autism group were not administered the visual distractor task due to poor compliance during the assessment session. Data were analyzed offline using custom made software, programmed in C# using Microsoft Visual Studio.

Procedure

All children were given one demonstration of the task by the examiner accompanied by a basic verbal explanation of the task tailored to each child's language ability. Participants were instructed to a) start at the start position at the bottom of the screen; b) keep the stylus in contact with the screen surface; c) continue the movement directly to the target; and d) in the visual distractor task, ignore the white distractor and continue to the red target. No time constraints were imposed. Participants were given one trial of each of the two tasks to practice, which were repeated until the participant was able to demonstrate understanding of the instructions. If required, a manual prompt was given during the practice trials to emphasize the requirement to maintain contact between the stylus and the screen. The task was commenced immediately following the practice trials. Task instructions were repeated as required.

Kinematic measures

Data from each trial were recorded as a series of time points and pixel position coordinates (x- and y-axis). Figure 2 shows the velocity time curve of a TD control, including labels to indicate the temporal arrangement of the kinematic variables. Movement initiation was determined by a visually evident departure from zero velocity, occurring within the starting position. Movement preparation time (MP) was defined as the time elapsed between first contact of the stylus on the starting position, and movement initiation (seconds). Total movement time (MT) was defined as the time (seconds) elapsed from movement initiation to movement termination upon reaching the boundary of the target. Other kinematic measures included peak velocity (meters/second), velocity asymmetry ratio (a ratio of time to reach peak velocity over the total movement time), number of peaks in velocity during movement execution, peak acceleration (meters/second^2), time to peak acceleration (seconds) and time from peak acceleration to movement termination (seconds). These were determined using customized interactive software. For the visual distractor task, spatial variation of movement from the direct path was calculated as the range of movement between the minimum and maximum vector coordinates on the x-axis (pixels). Within subject variability was defined as the standard deviation (SD) of each movement variable.

[place Figure 2 about here]

Data analysis

Trials excluded from further analysis (error trials) included incomplete movements where the stylus did not maintain contact with the screen for the entire movement; trials during which zero velocity was recorded part way through a movement (mid-movement stoppage); movements that made contact with the flanker distractor; movements that did not reflect compliance with task requirements (e.g., a curly line drawn between the start position and target); trials where the stylus was not placed on the starting position to begin; trials in which any part of the participant's body made contact with the screen; and impulsive movements. Impulsive movements were defined as trials in which after leaving the starting position, the movement proceeded in the opposite direction to the target (e.g. to the left of the vertical midline when a right target was presented). In trials where a target was situated on the vertical midline, an impulsive movement was defined as a movement that proceeded beyond the horizontal midline of the screen on a path that was in the direction of a flanking distractor or the left or right target position. Error trials as a proportion of the total number of trials for each participant in both the Simple Movement Task and the Visual Distractor Task (distractor condition only) were calculated for each participant.

The mean MP and MT were calculated for the sample, and individual movements were excluded if they fell more than three standard deviations above the mean. Seven outlier movements were excluded (6 autism, 1 TD): five movements were from the simple movement task; one movement was from the visual distractor task (no distractor condition); and one movement was from the visual distractor task (distractor condition). Left and right sided target movements were consolidated for the simple movement task analysis. Movements to the center target in the presence of a left or right sided distractor were consolidated for the visual distractor task. The mean (level) and standard deviation (variability) of each temporal and kinematic variable was calculated for each participant, for each target type (simple movement; center target without flanking visual distractor; central target with flanking visual distractor). Differences between left and right sided movements were not examined as this analysis was beyond the scope of the present paper. Totals of 347 movements and 282 movements were recorded in the

TD and autism groups respectively. In the TD group, 259 movements met the criteria for analysis. In the autism group, 185 movements met the criteria for analysis.

Regression analysis was used to examine the association between group and movement kinematic variables in the simple movement task. Random effects regression analysis was used to examine the association between distractor presence and movement kinematic variables in each group in addition to the group by distractor interaction. PIQ, age and gender were included as covariates in all regression analyses. Given Lemon, et al.'s (2010) finding that inhibitory control may demonstrate a difference between males and females with autism, gender effects were controlled. A mixed between-within subjects analysis of variance was conducted to assess the impact of movement condition (simple movement task, visual distractor task) on the proportion of errors across the autism and TD groups.

Results

Simple movement task

The mean level and variability of each of the kinematic measures for the autism and TD groups are shown in Table 2. Regression coefficients did not reveal a significant effect of group on the level of any kinematic variable. A regression model fit to the variability data revealed a significant effect of group only on variability of movement preparation time (p = .03). Specifically, the model estimated a .13 second greater variability in the movement preparation time in the autism group relative to the TD group after controlling for gender, age and PIQ.

Visual distractor task

The mean level and variability of the kinematic measures in both the no distractor and distractor conditions are shown in Table 2. From this data, the TD group appears to be more affected by the presence of a distractor than the autism group. A random effects regression model fit to these data found a significant effect of distractor presence on the level and variability in time from peak acceleration, in addition to a number of significant interactions between group and distractor. Namely, movement time, time to peak acceleration, variability in movement preparation time, and variability in time to peak acceleration revealed a significant interaction effect which was visible in the TD group demonstrating longer and more variable movement timing in the distractor condition. The autism group did not appear to adjust for distractor presence, except for a longer and more variable time from peak acceleration which was also observed in the TD control group.

PIQ and gender did not have any significant effect on movement for either group. Across the sample, increasing age was associated with shorter movement times, higher peak velocity, fewer peaks in velocity, and a smaller range of movement over the x-axis (i.e., more direct movement).

A mixed between-within subjects analysis of variance conducted to assess the impact of movement condition (simple movement task, visual distractor task) on the proportion of errors across the autism and TD groups did not find a significant interaction between group and movement condition (F [1,17] = 2.67, *p* = .12). No significant main effect was found for group (F [1,17] = 1.14, *p* = .30) or movement condition (F [1,17] = 3.97, *p* = .06), indicating that the proportion of error trials did not differ across the groups, or within groups across the movement tasks.

[place Table 2 about here]

Discussion

Upper-limb motor function has been well characterized in older children with autism, however, given the importance of early management of symptoms, it is important to know whether these findings generalize to young children. The aim of this study was to measure point-to-point upper-limb movement kinematics in young children (3-7 years) with autism using a touch screen task based on the tablet kinematic task of Rinehart, et al. (2006a), with adaptations based on the distractor interference task of Kritikos, et al. (2000). As anticipated, a significant difference in the preparation phase of movement was found in young children with autism. Specifically, these children demonstrated increased variability in the time taken to prepare simple point-to-point movements relative to typically developing controls. No difference was identified between groups in the execution phase of movement. These findings demonstrate some consistency with the point-to-point motor profile of older children and adolescents with autism described by Rinehart, et al. (2006a), outlining changes in the motor planning phase of movement in the context of intact movement execution. The present study demonstrates the robustness of this general upper-limb kinematic profile across different ages and methodologies in children with high-functioning autism.

While the older children in Rinehart, et al.'s (2006a) study demonstrated a significantly longer movement preparation, only increased *variability* in movement preparation time was found in the present examination of point-to-point kinematics in younger children with autism. That is, while children with autism on average took a similar time to the typically developing children to plan their movement, they were less consistent from trial-to-trial, sometimes giving less time to plan their movement, and sometimes taking longer. This disparity relative to Rinehart, et al. may reflect the methodological difference in the presentation of the point-to-point tasks in the present study (vertical touch screen requiring an upward aiming movement versus a horizontal tablet requiring a forward aiming movement in Rinehart, et al.), or an age related difference in motor preparation. Although developmental trajectories cannot be assumed from cross-sectional data, it is possible that the variability in movement preparation time in young children with autism translates to longer movement preparation time later in development relative to same age comparisons as differential rates of motor maturation are experienced relative to typically developing children. Given that variability of the kinematic variables was not examined by Rinehart, et al., it is also possible that increased variability within movements may be a phenomenon specific to motor function in autism that may contribute to the subtle movement differences exhibited. Although a majority of motor studies in autism have demonstrated a focus on the absolute level of the kinematic variables of interest, analysis of group variability has been found to distinguish the movement of individuals with autism from neurotypical children. In an examination of gait kinematics in ten children and adolescents with high-functioning autism (aged 6.8-14.4 years), Rinehart, Tonge, Bradshaw, Iansek, Enticott, and McGinley (2006b) found that children with autism demonstrated increased variability in stride length relative to typically developing children, despite equivocal performance on absolute kinematic measures. A longitudinal cohort study of point-to-point movement including measures of variability is required to further understand the developmental profile of movement preparation across childhood in autism.

An additional focus of the study was to explore the impact of a visual distractor on upper-limb kinematic motor performance in young children with autism. Consistent with the hypothesis, the children with autism showed no difference in their movement planning or execution, besides demonstrating a longer and more variable time from peak acceleration to movement termination, when a visual distractor was presented alongside the target endpoint in a point-to-point movement. In contrast, typically developing children were more variable in the time taken to plan their movement, and executed movements more slowly with a longer and more variable time to peak acceleration. This discrepancy may indicate that while typically developing children consider a visual distractor when planning and executing movement, this may not be the case for children with autism.

The automatic visual priming of alternative motor programs during voluntary movement may account for the slowed motor performance in typical controls in the presence of a visual distractor. In a review of voluntary movement control, Sumner and Husain (2008) described the automatic processes that are hypothesized to underlie flexibility in volitional movement. Namely, existing research suggests that visual stimuli prompt motor control processes to prepare motor programs for all possible movements that might be performed, thus increasing motor flexibility at the expense of the required movement. In the present study, the variable movement preparation time and slower execution recorded in typically developing controls in the presence of a visual distractor may reflect the additional time and neural resources required to prepare the alternative movement to the distractor, while temporarily delaying and slowing the required movement to the target. The absence of a substantial change in movement kinematics in the presence of a visual distractor in the children with autism suggests that the automatic priming of alternative motor plans was not undertaken.

One possible interpretation of this finding relates to a deficit in chaining together sequential actions as described by Fabbri-Destro, et al. (2009) and Cattaneo, et al. (2007). Specifically, these authors describe impairment in anticipatory action planning in autism, or the inability to consider future actions beyond the immediate goal. For example, in a study of motor organization in seven children with autism (age = 5.1-9 years; IQ > 70), Cattaneo, et al. found that typically developing children demonstrated anticipatory activation of the muscles of the mouth when reaching to grasp food, well before grasping and bringing the food to the mouth.

This was not observed in children with autism, who did not activate mouth muscles until they began to bring the food toward their mouth (i.e., when eating was the immediate goal). Given that the priming of alternative movements also demonstrates an anticipatory component, a deficit in anticipatory action planning may explain the absence of adjustment of movement kinematics in the presence of a distractor in the autism group.

Another possible interpretation for this finding is that dysexecutive factors in autism may interfere with processing of the entire visual field in order to undertake the automatic priming of alternate movements. The theory of weak central coherence in autism (Frith, 1989) would predict that when a situation necessitates divided attention, these children process local information at the expense of the visual 'gestalt' (Plaisted, Swettenham, & Rees, 1999). This interpretation is supported by the increase in time taken and variability at the end-stage movement control (shown by longer and more variable time from peak acceleration to movement end) observed in the autism group (and typically developing group) in the present study, possibly reflecting increased awareness of the distractor as the path taken entered the local vicinity of the target. A deficit in global processing has been proposed to influence motor planning in adults with autism (Glazebrook, et al., 2006), and is consistent with an inability to process sequential movements in autism as described by Fabbri-Destro, et al. (2009).

A deficit in visual perceptual integration may also explain the absence of automatic priming of movement alternatives in the autism group. This interpretation is consistent with the breadth of studies that have suggested a deficit in the integration of visual information to inform movement planning and execution in autism (Gepner & Mestre, 2002; Glazebrook, et al., 2006; Glazebrook, et al., 2009; Mari, et al., 2003; Masterton & Biederman, 1983; Minshew, Sung, Jones, & Furman, 2004). Difficulty processing or integrating extraneous visual information in order to inform movement may impact on automatic motor processes in volitional movement, as described by Sumner and Husain (2008). Thus, while the performance of the required movement is unchanged in the presence of a visual distractor, this may come at the expense of motor flexibility.

A limitation of the current study was the absence of endpoint precision required in the point-to-point movement. Endpoint precision was not obligatory as movement recording ceased when the stylus made first contact with the edge of the target, while in the adult study by Glazebrook, et al. (2006) and in Mari, et al.'s (2003) reach-to-grasp paradigm, task design necessitated endpoint precision. The observation that young participants often performed movements that extended beyond the target to the edge of the touch screen in the present study means that it is possible that the reduced requirement for movement precision may have masked differences in movement kinematics in the young children.

Further limitations of the current study relate to the small sample size, in addition to the small number of movement trials undertaken by each participant. The number of movement trials was limited in order to minimize the potential influence of attentional fatigue in young children, particularly those with autism. In addition, motivational factors may have influenced performance in the autism group to a greater extent than the controls. It has been stated that "although children with autism may cooperate with the general demands of the experimental situation, they may ignore more specific or more complex task requirements or put in less than maximal mental effort" (Garretson, Fein, & Waterhouse, 1990, p. 112). Therefore, motivation to perform is an important consideration in the interpretation of any motor study in children with autism.

In summary, the present exploration of upper-limb kinematics in young children with autism provides further support for an upper-limb motor profile of movement preparation differences which may be further influenced by a deficit in chaining movements, executive function, visual processing, visual-motor integration or a combination of these. These findings, in conjunction with prior studies of upper-limb kinematics (Glazebrook, et al., 2006; Rinehart. et al., 2006a), suggest that impaired motor preparation may be a stable clinical feature of autism in high-functioning children with the disorder. This requires confirmation with a longitudinal cohort study. If children with autism are unable to cohesively organize movements and modulate movement according to new visual information, this may account for why these children appear ‘clumsy’ and anecdotally appear to have more impaired motor function in less structured environments (e.g., in the playground) where coherent, flexible, and responsive movement is necessary to successfully navigate the social and physical environment. Future research should consider more ecologically valid experimental paradigms to investigate how the motor patterns observed in upper-limb tasks actually translate to everyday motor function.

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Author Note

Table 1

Mean and Standard Deviation (In Parentheses) of Age, Gender and IQ Measures for the Autism and TD Groups

	Group	
Characteristic	Autism (n = 11)	TD controls (n = 12)
Age (years)	6.2 (1.4)	6.6 (1.5)
Male/Female	8/3	9/3
Full scale IQ*	88.2 (16.9)	102.5 (11.1)
Performance IQ	94.0 (16.5)	101.0 (12.9)

* Indicates a domain of significant group difference

Table 2

Mean Group Values for the Level and Variability of the Kinematic Measures in the Simple Movement Task and the Visual Distractor Task

		Movement Preparation Time (sec)		Movement Time (sec)		Number of Peaks in Velocity		Peak Velocity (m/s)		Asymmetry Ratio		Peak Acceleration (m/s^2)		Time to Peak Acceleration (sec)		Time from Peak Acceleration (sec)	
		AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL	AUTISM	CONTROL
Level	Simple Movement Task																
	Simple Movement	.56	.48	1.03	.91	1.67	1.50	.47	.50	.59	.61	2.07	2.19	.31	.30	.73	.61
	Visual Distractor Task																
	No Distractor	.56	.42	.92	.81 [b]	1.58	1.43	.44	.47	.61	.62	2.12	2.20	.32	.24 [c]	.60	.56 [d]
	Distractor	0.54	0.52	.90	1.00	1.78	1.88	.42	.42	.64	.61	1.97	2.01	.24	.32	.66	.68
Variability	Simple Movement Task																
	Simple Movement	.32	.18 [a]	.30	.22	.79	.62	.11	.09	.15	.14	.97	.68	.20	.20	.26	.25
	Visual Distractor Task																
	No Distractor	.22	.12 [b]	.31	.17	.60	.54	.14	.12	.16	.13	1.07	.77	.21	.14 [b]	.29	.23 [d]
	Distractor	.24	.31	.29	.31	.82	.85	.11	.10	.15	.15	.83	.93	.18	.24	.33	.34

[a] A significant group difference exists, $p < .05$.
[b] A significant interaction effect between group and distractor presence, $p<.05$.
[c] A significant interaction effect between group and distractor presence, $p<.01$.
[d] A significant effect of distractor presence across both groups, $p<.05$.

Figure Caption

Figure 1. Sample touch screen layout for the simple movement task (a) and the visual distractor task (b).

Figure 2. Velocity time curve of a TD control child completing the simple movement task.

Figure 1.

TOP

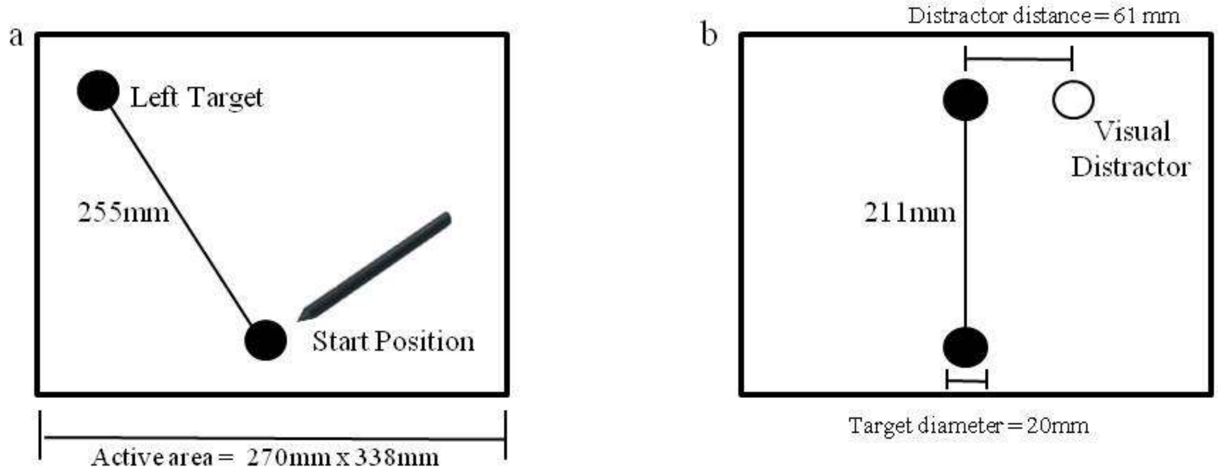
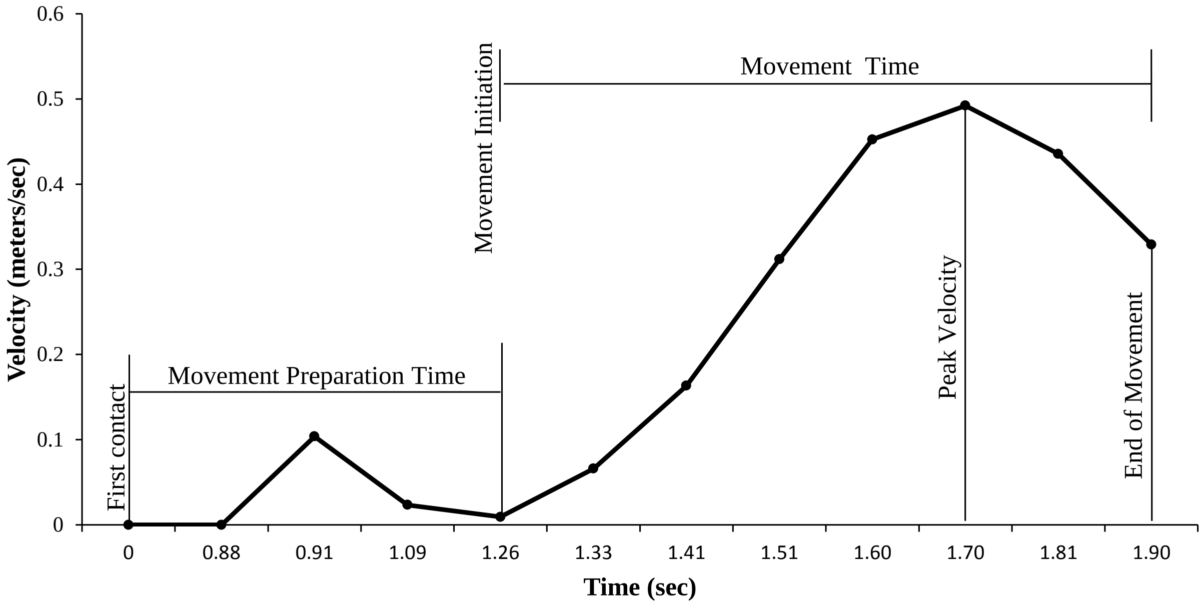

a
Left Target
255mm
Start Position
Active area = 270mm x 338mm
b
Distractor distance = 61 mm
Visual
Distractor
211mm
Target diameter = 20mm

Figure 2.

TOP



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