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Visual Feedback and Target Size Effects on Reach-to-Grasp Tasks in Children with Autism

Hsiu-Ching Yang · I-Chen Lee · I-Ching Lee

Abstract This study explores the effects of visual condition and target size during four reach-to-grasp tasks between autistic children and healthy controls. Twenty children with autism and 20 healthy controls participated in the study. Qualisys motion capture system and kinematic measures were used to record movement. Autistic group showed significantly longer movement time, larger normalized jerk score, more movement unit than controls, especially in non-visual feedback and small target blocks. Autistic group also showed significantly larger maximal grip aperture and normalized maximal grip aperture in visual feedback condition than controls. Autistic children demonstrate motor coordination problems and also depend on more visual cuing in high accuracy tasks. Autistic children develop other compensatory skills while performing tasks.

Keywords Autism · Kinematics · Reach to grasp · Visual feedback · Target size

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Introduction

Autism is a developmental disorder which is diagnosed on three main features: deficits in social interaction, deficits in communication, and stereotyped or restricted behavior. Numerous studies have shown the deficits in motor function of children with autistic spectrum disorders (ASD) by standard motor function assessments, such as Bruininks Oseretsky test (Ghaziuddin and Butler 1998), Test of Motor Impairment—Henderson Revision (Manjiviona and Prior 1995), and Movement Assessment Battery for Children (M-ABC) (Green et al. 2009; Miyahara et al. 1997). However, the standard motor function assessments provide scores according to the complete time of movement or the number of targeted behavior, although it could not quantify the process of movement.

Hand skills are strongly associated with our daily life, while reach-to-grasp movement is a foundation of a variety of hand manipulation. Kinematic analysis in reaching or reach-to-grasp movement is a precise way which measures the spatial and temporal process of the hand. Kinematic analysis of reaching or reach-to-grasp movement had been studied for individuals with obvious motor problem to identify their motor control problems, such as stroke (Fasoli et al. 2002; Wu et al. 2000), Parkinson's disease (Alberts et al. 2000), cerebellar patients (Rand et al. 2000), and children with cerebral palsy (Chang et al. 2005. These studies often used normalized jerk score (NJS) and movement unit (MU) to display the performance of motor smoothness and coordination (Alberts et al. 2000; Chang et al. 2005; Fasoli et al. 2002; Wu et al. 2000). Nevertheless, these kinematic variables were often affected by task demands, which was a more challenge to motor coordination in higher accuracy tasks. A common task demand included target size hence, grasping a smaller target was

considered a higher accuracy task (Alberts et al. 2000; Chang et al. 2005).

Previous studies have explored motor impairments from varied kinematic analysis of upper limbs movements (such as manual aiming, point-to-point, reach-to-grasp, and reach-and-drop) and focused on deficits in motor planning and motor execution in ASD (Dowd et al. 2012; Forti et al. 2011; Glazebrook et al. 2009, 2006; Mari et al. 2003; Rinehart et al. 2006; Stoit et al. 2013). Glazebrook et al. (2006, 2009) found that young adults with ASD required longer reaction time to plan manual aiming movement, and longer movement time (MT) and larger travelling amplitude to execute the movement, so they speculated that ASD had difficulty in motor planning and execution. Rinehart et al. (2006) and Dowd et al. (2012) examined point-to-point in young adults (Rinehart et al. 2006) and young children with ASD (Dowd et al. 2012), autistic group showed slow and different movement preparation time in both two studies. Forti et al. (2011) investigated a reach-and-drop task in preschool children with autism, they found autism perform longer MT and additional MUs than controls. They suggested that children with autism required more corrective sub movements (Forti et al. 2011). Stoit et al. (2013) explored that cueing information affect grasping movement in children and adolescents with ASD, their findings didn't show different accuracy and reaction time between ASD and controls, but appeared longer MT in ASD. They speculated that impaired motor execution rather than motor planning in ASD (Stoit et al. 2013). Mari et al. (2003) used ELITE motion analysis system to examine the reach-to-grasp movement in children with ASD. They found that ASD had longer MT, longer deceleration time, smaller peak velocity (PT), and longer time to maximal grip aperture (MGA) than age-matched controls. Notwithstanding, no previous study has reported the performance of movement smoothness (i.e., NJS and MU) from a kinematic measurement during reach-to-grasp movement in autism.

Furthermore, executing reach-to-grasp movement needs well sensorimotor processing, but autism usually have abnormal characteristics in certain sensory processing (Baranek et al. 2005; Tomchek 2003). Numerous studies have provided questionnaire assessments to evaluate sensory dysfunction in autism, such as sensory profile (SP) (Kern et al. 2006; Kientz and Dunn 1997), short sensory profile (SSP) (Liu 2013; Tomchek and Dunn 2007), Sensory Experiences Questionnaire (SEQ) (Baranek et al. 2006), and Diagnostic Interview for Social and Communication Disorders (Leekam et al. 2007). These studies indicated that 69–95 % individuals with ASD have sensory abnormalities (Baranek et al. 2006; Kern et al. 2006; Kientz and Dunn 1997; Leekam et al. 2007; Liu 2013; Tomchek and Dunn 2007), and it may be specific in some

domains: auditory (Kern et al. 2006; Kientz and Dunn 1997; Tomchek and Dunn 2007), vision(Kern et al. 2006; Leekam et al. 2007), touch(Kern et al. 2006; Kientz and Dunn 1997; Tomchek and Dunn 2007), smell/taste (Leekam et al. 2007), and movement(Kientz and Dunn 1997). Some studies have reported that autism seems to depend on more visual or proprioceptive inputs than normal children in the postural control testing (Minshew et al. 2004; Molloy et al. 2003), and have difficulty and more time in utilizing visual information to perform upper limbs movement (Dowd et al. 2012; Glazebrook et al. 2009). However, Fuentes et al. (2011) have used the KINARM (BKIN Technologies) to assess the proprioception of elbow and finger joints in autism, they didn't find significant primary proprioceptive deficits in autism. Researchers administer the kinematic analysis in this study to explore the motor control and to investigate target size effect on reach-to-grasp movement in autism. Also, researchers explore visual reliance under two experimental conditions: one with visual feedback and the other with non-visual feedback. The main purposes of the present study are to compare the kinematic performance of the reach-to-grasp movement between children with autism and controls, and to examine the effects of target size and visual feedback.

Methods

Participants

Two groups were recruited in this study: autism (n = 20; 18 male, 2 female; mean age 7 year 8 months, SD 1 year 4 months), and controls (n = 20; 11 male, 9 female; mean age 7 year 9 months, SD 1 year 5 months). Controls were matched according to age and handedness (right: left = 9:1), and above 15th percentile of M-ABC to exclude motor impairment. Subjects with autism were diagnosed according to Diagnostic and Statistical Manual of Mental Disorders, 4th edition (DSM-IV) by child psychiatrists and confirmed by Gilliam Autism Rating Scale—2nd edition (GARS-2).

All participants were prescreened to exclude children with low cognitive functioning, visual perception problem, and musculoskeletal impairment: (1) Peabody Picture Vocabulary Test-Revised (PPVT-R) and standard score were above 85, its coefficients correlated to Wechsler intelligence scales are among .44–.69 which can be applied to measure cognitive function; (2) Visual Perception Test from The Berry-Buktenica Developmental Test of Visual-Motor Integration; (3) Physical examination to check the muscle tone and range of motion. Exclusion criteria of all participants were: epilepsy; limbs, neurological, visual and hearing impairments; and other definite medical diagnosis

Fig. 1 The reach-to-grasp task in the present study. **a**, **b** With visual feedback condition, **c** three markers placed on the testing hand, **d**, **e**, **f** with non-visual feedback condition. **a** Visual feedback condition: at beginning, subject was asked to face the table and sat on the height-adjustable chair to let the elbow flex 90° (testing hand: *right*) 1 starting position, 2 target. The distance between 1 and 2 was 60 % AL. **b** Visual feedback condition: movement end, subject grasped the target. **c** Three markers placed on the testing hand. 4 on lateral styloid process of the wrist to record reaching component 5 and 6: on the nails of thumb and index finger to record grasping component. **d** Non-visual feedback condition: at beginning, subject could see the target for 4 s. **e** Non-visual feedback condition: before movement starting, a 30 × 30 cm shroud to shelter the subject's vision. **f** Non-visual feedback condition: movement end, subject grasped the target with the shroud to shelter the subject's vision
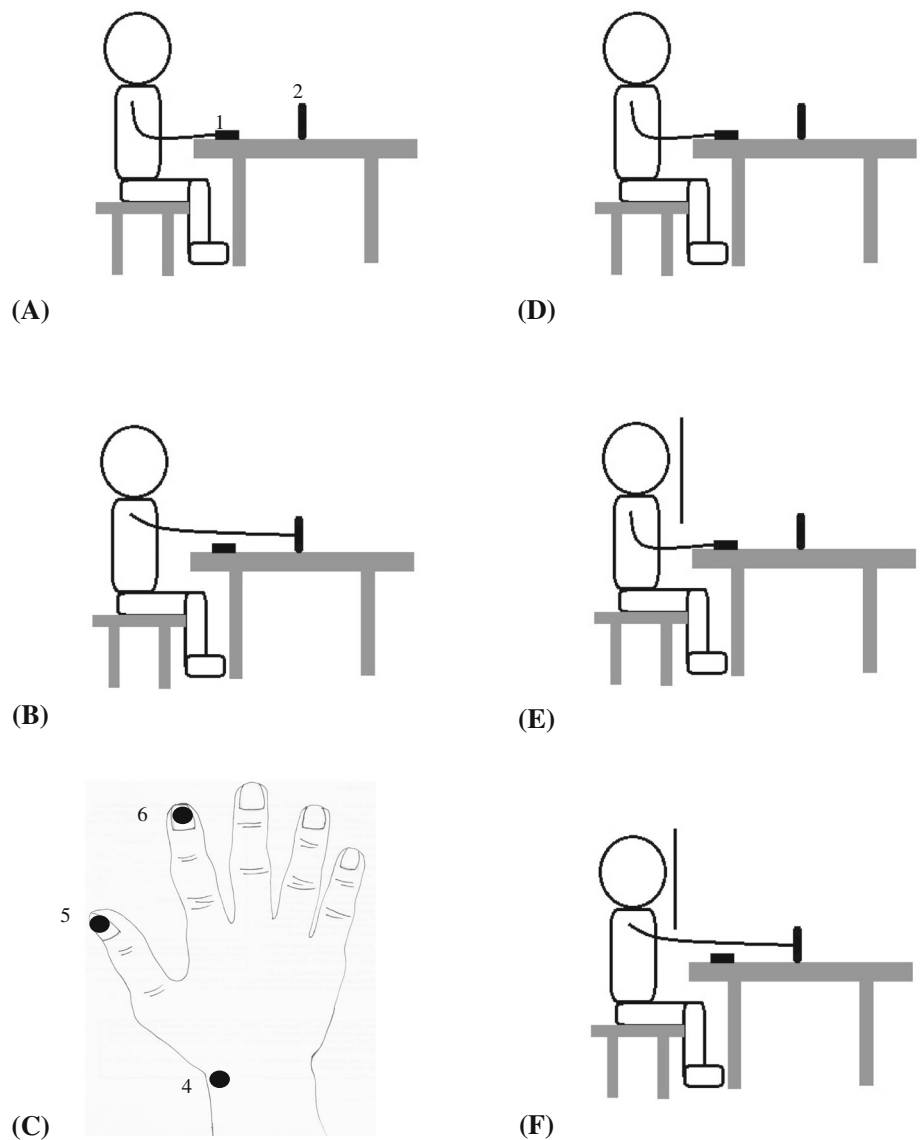
(e.g. attention deficit hyperactivity disorder) or genetic disorders (e.g. Fragile × disorder).

This study was approved by human experiment and ethics committee of National Cheng Kung University Hospital. All participants or their guardians in this study received complete explanation, and accepted to participate. Written informed consents of all participants were obtained.

Apparatus

Qualisys motion capture system (Qualisys, Partille, Sweden) was used to recorded reach-to-grasp movement by five infrared light emitting diodes cameras to capture the light reflected from three passive markers (diameter: 1 cm) placed on the testing hand (preferred hand). One of the three markers was placed on lateral styloid process of the wrist to record reaching component, and another two were placed on the nails of thumb and index finger to record grasping component (Fig. 1c). The sampling rate was 100 Hz. Low pass filtered raw data by Butterworth filter with a second order and a cut-off frequency of 6 Hz.

Procedure

Subjects were asked to face the table and sat on the height-adjustable chair to let the elbow flex 90°. Non-testing hand was placed on ipsilateral knee comfortably. The target was placed on the midline of the subject, and the distance between starting position and target was 60 % arm length (AL, the length from acromion to lateral styloid process), as shown in Fig. 1a. Although, the targets were cylinders

Table 1 The relationships of target distance with Arm length, and target size with finger span

Arm length (cm)	Target distance (cm)	Finger span (cm)	Target diameter (cm)	
			Small	Large
30.0–39.9	21	9.0–12.9	1.1	2.75
40.0–49.9	27	13.0–16.9	1.5	3.75
50.0–59.9	33	17.0–20.9	1.9	4.75

and the height were all 10 cm. However, the sizes of targets were large versus small, which were modified from the design of (Kuhtz-Buschbeck et al. 1998a, b), the diameter of the large one was 25 % finger span (FS, the maximal length between thumb to index fingertip while thumb and index are opening) while the diameter of the small one was 10 % FS. As shown in Table 1, the relationships between target distance with AL, and target size with FS were designed in present study.

Two visual testing conditions: visual-feedback (eyes open) and non-visual feedback (eyes open, but using a 30 × 30 cm shroud to shelter the subject's vision, Fig. 1e, f) were divided into two experimental blocks, nevertheless, the sequence for testing was arranged in a counterbalanced. In non-visual feedback condition, the subjects could see the target for 4 s (Fig. 1d) and then shelter their vision. The size testing sequence was also randomly divided into two experimental blocks in each visual condition. Thus, there were four experimental blocks, five trials per block, and 20 trials in total. Hence, each subject was allowed to perform in his comfortable pace just as he grasped ordinarily. Two practice trials in each block were allowed to assure the understanding of task requirement and proper rest were arranged if needed.

Kinematic Variables

The movement of raw data (the position of x, y, z) was converted into kinematic variables using computer program of Matlab 7.1. The following variables were used in this study: (1) reaching component: MT, PV, percent of time to PV (PTPV), NJS, and MU; (2) grasping component: MGA, normalized MGA (NMGA), and percent of time to MGA (PTMGA).

The definitions of variables have been provided as follows. PV is the maximal velocity of reaching. Movement onset is defined as the velocity exceeds 5 % of PV of that movement. Movement end on the other hand is defined as the velocity is below 5 % of PV and grip aperture should stay consistent to represent until the subject have grasped the target. In addition, PV relates to the force. Thus, larger PV means larger force induced by executing movement (Chang et al. 2005; Fasoli et al. 2002). In the same vein,

time to PV is defined as the time from movement onset to PV, the acceleration time (Fasoli et al. 2002; Kuhtz-Buschbeck et al. 1998b; Marteniuk et al. 1987). Moreover, PTPV is defined as the percentage of time to PV in MT. Hence, larger PTPV represents larger ratio of acceleration time and smaller ratio of deceleration time. We correct movement trajectory to grasp object accurately by instantaneous feedback in deceleration time (Chang et al. 2005; Fasoli et al. 2002; Marteniuk et al. 1987), although shorter deceleration time suggest shorter correctional time and better movement strategy.

Normalized jerk score and MU are indicators of movement smoothness and facileness. NJS is derived from the three order differentiation of position to represents the smoothness of movement trajectory. Larger NJS means worse smoothness and poorer coordination (Alberts et al. 2000; Chang et al. 2005). A MU is defined as an acceleration phase and a deceleration phase, since it can represent the facileness of movement (Fasoli et al. 2002). Thus, more numbers of MU mean larger number of correctional times and poorer motor coordination.

In addition, MGA is the maximal distance between thumb and index fingertips during the prehension process that should be adjusted according to target size. NMGA is the ratio of MGA to each subject's finger span. Time to MGA is the time from movement onset to MGA, and its percentage in MT is PTMGA (Kuhtz-Buschbeck et al. 1998b). Therefore, Smyth et al. (2001) on this note, stated that when the degree of task difficulty is higher, PTMGA would be smaller, which means MGA occurs earlier.

Statistical Analysis

SPSS17.0 statistic software was used. Descriptive statistics and independent t tests were carried out to examine the differences in age, AL, FS, PPVT-R, visual perception standard score between two groups. The kinematic variables of each subject analyzed into Analysis of Variances (ANOVAs) were averages for each experimental block. ANOVAs were applied to analyze the effects of group (between-subjects factor), target size and visual condition (within-subjects factors) on kinematic variables. Post-hoc analysis of independent t tests were used to explore differences in each condition between two groups, and a series of paired t tests for intra-group with significant level was corrected by bonferroni correction were used to examine the effects of visual condition and/or target size.

Results

There were no significant differences on age, AL, FS, and visual perception between the two groups (Table 2).

Table 2 Subjects information

	Autism (n = 20) mean (SD)	Control (n = 20) mean (SD)	t	p
Age	7 year 8 months (1 year 4 months)	7 year 9 months (1 year 5 months)	−.224	.824
Arm length (cm)	40.78 (4.13)	38.65 (3.51)	1.752	.088
Finger span (cm)	12.98 (.94)	12.46 (1.36)	1.391	.172
PPVT-R standard score	106.55 (18.96)	116.85 (12.02)	−2.052	.048*
Visual perception standard score	95.75 (12.03)	103.90 (15.56)	−1.853	.072

* $p < .05$

Nevertheless, autism had significantly lower performance than controls in PPVT-R standard score.

Mean values of kinematic variables were calculated for each experimental block in each subject (Table 3). Every mean value for each experimental block from each subject consisted of at least three trials due to some trials failing in capturing the movement onset or movement end. Totally, 767 trials were analyzed.

Reaching Component

Summary of ANOVAs analysis in each kinematic variable was shown in Table 4.

Movement Time (MT)

Both groups revealed significantly longer MT in non-visual feedback condition and in small target blocks. Furthermore, autistic group took significantly longer MT than controls when grasping small target (Fig. 2).

Analysis of MT showed that there were significant main effects of group, visual and size; and a significant interaction of size × group (Table 4). As shown in Fig. 2, post hoc analysis showed that children with autism had significantly longer MT in small target [both visual condition ($t_{(38)} = 2.214$, $p = .033$) and non-visual condition ($t_{(38)} = 2.961$, $p = .005$)] than controls. Thus, after separating 2 × 2 ANOVAs for two groups, both revealed significant main effects of visual (autism: $F_{(1,19)} = 32.119$, $p < .001$; normal: $F_{(1,19)} = 24.846$, $p < .001$) and size (autism: $F_{(1,19)} = 26.429$, $p < .001$; normal: $F_{(1,19)} = 19.467$, $p < .001$), but no other significant interaction effect was found.

Peak Velocity (PV) and Percent of Time to Peak Velocity (PTPV)

All participants showed smaller PV and smaller PTPV in non-visual feedback condition and in small target blocks. The results of PV and PTPV did not appear significantly different between two groups.

Analysis of PV revealed that there were significant main effects of Visual, and Size, whereas no other interaction was found (Table 4). PTPV showed only main effects of Visual, and Size, but no significant interaction effect was found (Table 4).

Normalized Jerk Score (NJS)

Both groups showed significantly larger NJS in non-visual feedback condition and in small target blocks. Moreover, autistic group showed significantly larger NJS than controls in visual-small, non-visual-large, and non-visual-small block (Fig. 3).

Analysis of NJS indicated significant main effects of Group, Visual, and Size; and significant interaction effects of visual × group, size × group (Table 4). Post-hoc analysis indicated that autistic group had significantly larger NJS in visual-small ($t_{(38)} = 2.275$, $p = .029$), non-visual-large ($t_{(38)} = 2.578$, $p = .014$), and non-visual-small ($t_{(38)} = 3.541$, $p = .001$) blocks than controls as shown in Fig. 3. Hence, separate 2 × 2 ANOVAs showed that there were significant main effects of Visual (autism: $F_{(1,19)} = 21.389$, $p < .001$; normal: $F_{(1,19)} = 14.946$, $p = .001$) and Size (autism: $F_{(1,19)} = 11.569$, $p = .003$; normal: $F_{(1,19)} = 17.865$, $p < .001$) in two groups, whereas no significant interaction of visual and size.

Movement Unit (MU)

Autistic group appeared significantly more MU than control group in all blocks (Fig. 4). Autistic group needed significantly more MU in non-visual feedback condition and in small target blocks, while control group showed significantly more MU only in non-visual feedback condition.

Analysis of MU revealed that there were significant main effects of group, visual, and size; and significant interactions of visual × group and size × group (Table 4). Figure 4 showed the results of post hoc analysis that children with autism had significantly larger MU than the controls in all block (all $p < .05$). The results of 2 × 2

Table 3 Kinematic data in two groups

Variables	Autism				Control			
	Visual		Non-visual		Visual		Non-visual	
	Large	Small	Large	Small	Large	Small	Large	Small
MT (s)	.92 (.20)	1.11 (.27)	1.29 (.31)	1.54 (.44)	.88 (.19)	.94 (.20)	1.11 (.32)	1.18 (.32)
PV (mm/s)	810.55 (196.79)	718.92 (172.16)	655.41 (167.11)	607.83 (136.73)	743.18 (173.46)	687.77 (139.57)	659.03 (152.43)	658.27 (133.05)
PTPV (%)	39.10 (6.22)	34.49 (8.27)	28.80 (5.89)	27.08 (7.32)	36.11 (5.74)	34.66 (5.49)	29.10 (5.41)	27.60 (6.90)
NJS	88.48 (47.09)	143.93 (106.56)	235.77 (173.25)	366.98 (278.40)	66.97 (26.95)	85.97 (40.37)	127.59 (72.06)	137.14 (82.13)
MU	2.36 (.93)	3.03 (1.20)	4.08 (1.43)	4.88 (1.77)	1.73 (.60)	1.94 (.68)	2.58 (1.05)	2.59 (1.15)
MGA (mm)	103.33 (14.65)	90.42 (15.95)	104.97 (15.31)	97.94 (15.94)	83.83 (12.23)	71.10 (11.05)	101.10 (12.65)	91.78 (12.11)
NMGA (%)	79.76 (9.22)	69.70 (11.58)	80.83 (9.56)	75.40 (10.36)	67.35 (6.86)	57.08 (6.19)	81.29 (7.18)	73.93 (8.60)
PTMGA (%)	59.57 (7.75)	54.47 (9.61)	49.68 (7.50)	46.85 (9.14)	60.65 (8.82)	57.81 (9.20)	50.23 (7.54)	48.71 (8.72)

MT movement time, *PV* peak velocity, *PTPV* percent of time to peak velocity, *NJS* normalized jerk score, *MU* movement unit, *MGA* maximal grip aperture, *NMGA* normalized maximal grip aperture, *PTMGA* percent of time to maximal grip aperture

ANOVA for autistic group revealed main effects of Visual ($F_{(1,19)} = 58.509$, $p < .001$) and Size ($F_{(1,19)} = 16.965$, $p = .001$); while that for control group showed a main effect of Visual ($F_{(1,19)} = 14.503$, $p = .001$), although no significant interaction effect was found in each group.

Grasping Component

Maximal Grip Aperture (MGA)

Autistic group used significantly larger MGA than control group in visual feedback condition, but not in non-visual feedback condition (Fig. 5). Besides, control group showed significantly larger MGA in non-visual feedback condition and in large target blocks. However, unlike controls, autistic group showed significantly larger MGA when grasping large target only in visual feedback condition; and significantly larger MGA without visual information only in small target blocks.

Analysis of MGA showed that there were significant main effects of group, visual, and size; and significant interactions of visual × group and visual × size (Table 4). Post-hoc analysis showed that children with autism had significant larger MGA than the controls in visual condition [both large target ($t_{(38)} = 4.570$, $p < .001$) and small target ($t_{(38)} = 4.455$, $p < .001$)], but there were no significant differences between two groups in non-visual condition (Fig. 5). However, the results of 2 × 2 ANOVAs for control group revealed significant main effects of visual ($F_{(1,19)} = 78.143$, $p < .001$) and Size ($F_{(1,19)} = 46.894$, $p < .001$); and for autistic group showed significant main effects of Visual ($F_{(1,19)} = 8.978$, $p = .007$) and Size ($F_{(1,19)} = 29.277$, $p < .001$), and a significant interaction of Visual × Size ($F_{(1,19)} = 6.894$, $p = .017$). In the post hoc analysis of paired t-tests in autistic group, the results indicated that there were a significant effect of Size in visual condition ($t_{(19)} = 6.306$, $p < .001$, bonferroni corrected), and a significant effect of Visual in small target ($t_{(19)} = 3.891$, $p = .001$, bonferroni corrected).

Normalized Maximal Grip Aperture (NMGA)

The results of NMGA were similar to MGA, autistic group showed significantly larger NMGA than control group in visual feedback condition, but not in non-visual feedback condition (Fig. 6). Besides, control group showed significantly larger NMGA in non-visual feedback condition and in large target blocks. However, unlike controls, autistic group showed significantly larger NMGA when grasping large target only in visual feedback condition; and significantly larger MGA without visual information only in small target blocks.

Table 4 Summary of ANOVAs analysis in each kinematic variable

Variables	Main effect			Interaction effect			
	Group	Visual	Size	Group × visual × size	Group × visual	Group × size	Visual × size
MT (s)	$F_{(1,38)} = 5.800$ $p = .021*$	$F_{(1,38)} = 55.901$ $p < .001**$	$F_{(1,38)} = 39.895$ $p < .001**$	$F_{(1,38)} = .511$ $p = .479$	$F_{(1,38)} = 3.911$ $p = .055$	$F_{(1,38)} = 11.420$ $p = .002**$	$F_{(1,38)} = 1.078$ $p = .306$
PV (mm/s)	$F_{(1,38)} = .065$ $p = .801$	$F_{(1,38)} = 24.724$ $p < .001**$	$F_{(1,38)} = 16.497$ $p < .001**$	$F_{(1,38)} = .047$ $p = .830$	$F_{(1,38)} = 3.989$ $p = .055$	$F_{(1,38)} = 2.979$ $p = .092$	$F_{(1,38)} = 4.053$ $p = .051$
PTPV (%)	$F_{(1,38)} = .080$ $p = .779$	$F_{(1,38)} = 149.965$ $p < .001**$	$F_{(1,38)} = 11.785$ $p = .001**$	$F_{(1,38)} = 2.520$ $p = .121$	$F_{(1,38)} = 1.971$ $p = .168$	$F_{(1,38)} = 1.571$ $p = .218$	$F_{(1,38)} = 2.342$ $p = .134$
NJS	$F_{(1,38)} = 11.891$ $p = .001**$	$F_{(1,38)} = 32.069$ $p < .001**$	$F_{(1,38)} = 15.149$ $p < .001**$	$F_{(1,38)} = 3.433$ $p = .072$	$F_{(1,38)} = 9.223$ $p = .004**$	$F_{(1,38)} = 8.177$ $p = .007**$	$F_{(1,38)} = 2.079$ $p = .158$
MU	$F_{(1,38)} = 20.312$ $p < .001**$	$F_{(1,38)} = 68.828$ $p < .001**$	$F_{(1,38)} = 18.828$ $p < .001**$	$F_{(1,38)} = .977$ $p = .329$	$F_{(1,38)} = 11.345$ $p = .002**$	$F_{(1,38)} = 10.140$ $p = .003**$	$F_{(1,38)} = .031$ $p = .861$
MGA (mm)	$F_{(1,38)} = 9.760$ $p = .003**$	$F_{(1,38)} = 79.899$ $p < .001**$	$F_{(1,38)} = 73.625$ $p < .001**$	$F_{(1,38)} = .560$ $p = .459$	$F_{(1,38)} = 29.835$ $p < .001**$	$F_{(1,38)} = .187$ $p = .668$	$F_{(1,38)} = 7.947$ $p = .008**$
NMGA (%)	$F_{(1,38)} = 7.825$ $p = .008**$	$F_{(1,38)} = 77.637$ $p < .001**$	$F_{(1,38)} = 77.869$ $p < .001**$	$F_{(1,38)} = .427$ $p = .517$	$F_{(1,38)} = 31.785$ $p < .001**$	$F_{(1,38)} = .322$ $p = .574$	$F_{(1,38)} = 8.277$ $p = .007**$
PTMGA (%)	$F_{(1,38)} = .687$ $p = .412$	$F_{(1,38)} = 67.059$ $p < .001**$	$F_{(1,38)} = 9.602$ $p = .004**$	$F_{(1,38)} = .070$ $p = .793$	$F_{(1,38)} = .199$ $p = .658$	$F_{(1,38)} = .812$ $p = .373$	$F_{(1,38)} = .949$ $p = .336$

MT movement time, *PV* peak velocity, *PTPV* percent of time to peak velocity, *NJS* normalized jerk score, *MU* movement unit, *MGA* maximal grip aperture, *NMGA* normalized maximal grip aperture, *PTMGA* percent of time to maximal grip aperture
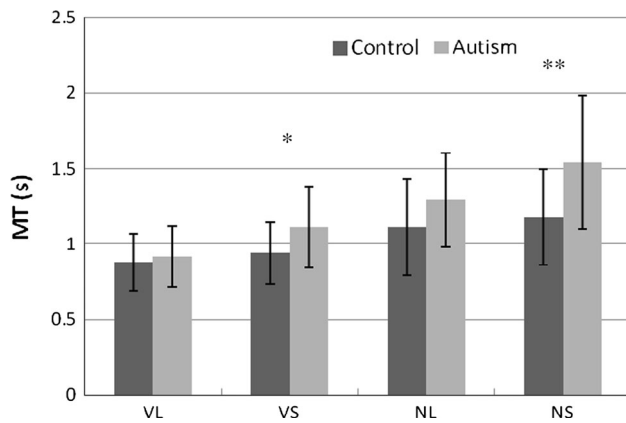
* $p < .05$; ** $p < .01$

Fig. 2 Comparison of the means (standard deviation) of MT (movement time) between two groups in four experimental blocks (*VL* visual feedback with large target, *VS* visual feedback with small target, *NL* non-visual feedback with large target, *NS* non-visual feedback with small target). *$p < .05$; **$p < .01$
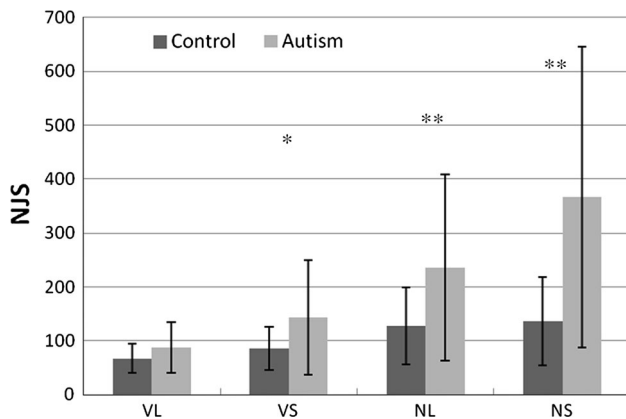

Fig. 4 Comparison of the means (standard deviation) of MU (movement unit) between two groups in four experimental blocks (*VL* visual feedback with large target, *VS* visual feedback with small target, *NL* non-visual feedback with large target, *NS* non-visual feedback with small target). *$p < .05$; **$p < .01$

Fig. 3 Comparison of the means (standard deviation) of NJS (normalized jerk score) between two groups in four experimental blocks (*VL* visual feedback with large target, *VS* visual feedback with small target, *NL* non-visual feedback with large target, *NS* non-visual feedback with small target). *$p < .05$; **$p < .01$

Fig. 5 Comparison of the means (standard deviation) of MGA (maximal grip aperture) between two groups in four experimental blocks (*VL* visual feedback with large target, *VS* visual feedback with small target, *NL* non-visual feedback with large target; *NS* non-visual feedback with small target). * $p < .05$; ** $p < .01$

Analysis of NMGA revealed significant main effects of group, visual, size; and significant interactions of visual × group and visual × size (Table 4). As shown in Fig. 6, post hoc analysis of t-tests revealed that autistic group had significantly larger NMGA than normal group in visual condition [large target ($t_{(38)} = 4.830$, $p < .001$) and small target ($t_{(38)} = 4.298$, $p < .001$)]. Also, separate 2 × 2 ANOVAs of NMGA for each group showed that there were significant main effects of visual ($F_{(1,19)} = 74.316$, $p < .001$) and size ($F_{(1,19)} = 52.464$, $p < .001$) in control group; but there were significant main effects of visual ($F_{(1,19)} = 8.457$, $p = .009$) and size ($F_{(1,19)} = 29.402$, $p < .001$), and a significant interaction of visual × size ($F_{(1,19)} = 6.989$, $p = .016$) in children with autism. Therefore, autistic group showed a significant effect of Size in visual condition ($t_{(19)} = 6.249$, $p < .001$,
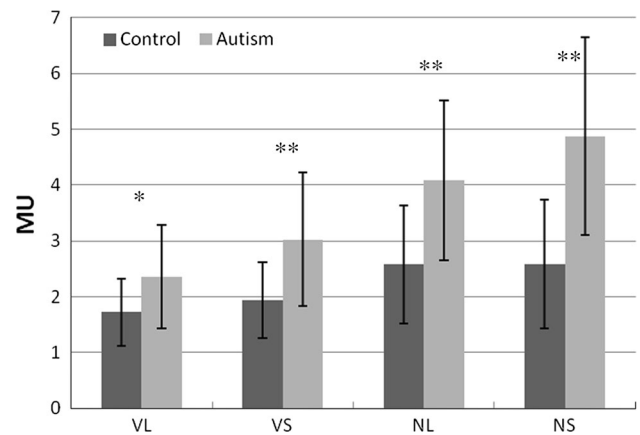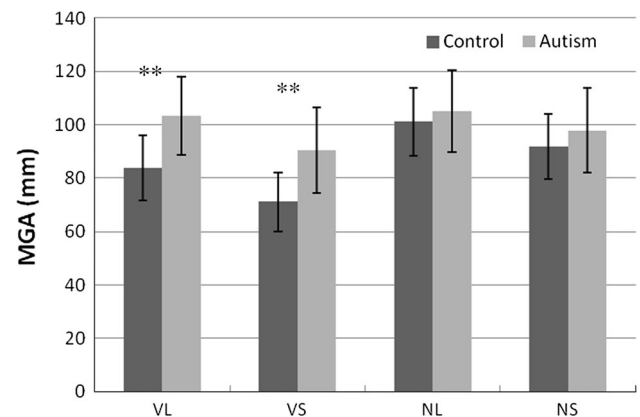
bonferroni corrected), and a significant effect of visual in small target ($t_{(19)} = 3.919$, $p = .001$, bonferroni corrected) by paired *t* tests.

Percent of Time to Maximal Grip Aperture (PTMGA)

All participants showed smaller PTMGA in non-visual feedback condition and in small target blocks. The results of PTMGA did not appear significantly different between two groups.

Analysis of PTMGA indicated that there were significant main effects of Visual and Size, and no other interaction was found (Table 4).
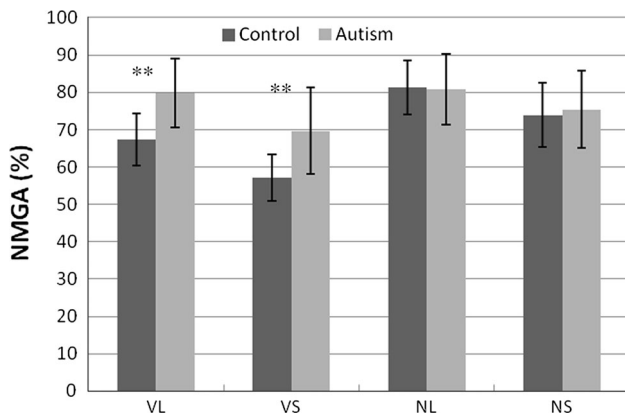
Fig. 6 Comparison of the means (standard deviation) of NMGA (normalized maximal grip aperture) between two groups in four experimental blocks (*VL* visual feedback with large target, *VS* visual feedback with small target, *NL* non-visual feedback with large target, *NS* non-visual feedback with small target). $*p < .05$; $**p < .01$

Discussion

In present study, some kinematic variables in both groups were affected by both visual condition and target size. Especially, children with autism as well as controls showed longer MT, smaller PV, smaller PTPV, larger NJS, and smaller PTMGA in non-visual feedback and small target blocks. Thus, these findings were consistent with previous studies (Jakobson and Goodale 1991; Kuhtz-Buschbeck et al. 1998a, b; Smyth et al. 2001). Also, in the absence of visual information and higher task-accuracy, both groups needed longer executing time and longer correctional phrase. Similarly, if MGA occurred earlier, the motor smoothness was more influenced.

Autistic group in this study appeared significantly longer MT, larger NJS, more MU, larger MGA, and larger NMGA than healthy controls in visual feedback condition; significantly larger NJS and more MU than healthy controls in non-visual feedback condition; and significantly longer MT, larger NJS, and more MU than healthy controls when grasping small target. This result supports the fact that children with autism have motor coordination problems and thus may depend on more visual information, as the problems of motor control are threatened more by task demands (such as target size). The visual feedback conditions, is consistent with Mari et al. (2003) who found that autism showed longer MT. Nevertheless, autistic group in this study appeared significantly longer MT, larger NJS, more MU, larger MGA, and larger NMGA than controls. These findings are similar to numerous motor impairment patients: Parkinson's disease (Alberts et al. 2000), cerebellar patients (Rand et al. 2000), and children with cerebral palsy (Chang et al. 2005). In accordance with Forti et al.'s (2011) autistic group performed more MU during reach-and-drop task, autistic group in this study also appeared more MU during reach-to-grasp movement, that is, children

with autism require additional corrective sub movements in movement execution process. Hence, it seems that children with autism not only have long executive time, poor motor coordination, jerky movement pattern but also use larger grip aperture to compensate lower accuracy of reaching movement, therefore, the performance were more influenced in the high accuracy-demand task (small target). As previous studies suggested that increases in maximal grasp aperture may serve to compensate for errors in reaching accuracy (Karl et al. 2012; Wing et al. 1986), children with autism seem to use a movement strategy of larger grip aperture to compensate lower accuracy of reaching movement. In non-visual feedback condition, autistic group showed larger NJS and MU which indicate that motor coordination and smoothness become impaired without visual information. This finding is in line with that of cerebellar patients who could apply visual information to enhance the accuracy of reaching movement (Day et al. 1998).

One of main interesting finding in present study is that autistic group showed significantly larger MGA and NMGA in visual feedback condition than controls, but they didn't show significantly larger MGA and NMGA in non-visual feedback condition than healthy controls. Besides, MGA and NMGA of autistic group have only a significant effect of Visual in small target, but not in large target; only a significant effect of Size in visual feedback condition, but not in non-visual feedback condition. Nevertheless, for control group, the results of MGA and NMGA revealed significant main effects of visual and size. First, similar to healthy controls, children with autism seemed to scale their grip aperture according to target size when the visual information was available. However, unlike healthy controls, autistic group didn't appear to scale their grip aperture according to target size without visual cuing. Second, children with autism didn't show larger grip aperture in the task of non-visual-large block than in the task of visual-large block. The possible reason may be that the finger span has a limited range. Children with autism use the extreme larger MGA to grasp a target under with- and without- visual information to compensate lower accuracy of reaching movement, especially when they intended to grasp a large target. The mean of MGA in autistic group in performing task of non-visual-large block was only > 1.64 mm than in the task of visual-large block, whereas the control group was 17.27 mm. Comparatively, the MGA of healthy controls was significantly smaller with proper visual cuing, that was in agreement with the previous finding of normal adult and children studies (Jakobson and Goodale 1991; Kuhtz-Buschbeck et al. 1998a, b).

This study did not find significant difference in temporal kinematic variables (PTPV and PTMGA) between autism and controls, these results were similar to Glazebrook et al.'s (2006) finding that autistic adult whose proportional time after peak velocity did not significantly differ from

normal adult and Forti et al.'s (2011) finding that there was no significant difference of asymmetry index between autism and control children. It seems compatible with Glazebrook et al.'s (2006) and Forti et al.'s (2011) arguments, the movement structure of autism is likely to be intact.

From the perspective of motor control (Shumway-Cook and Woollacott 2001), two types of peripheral sensation: visual (i.e. location and size of target) and somatosensory (i.e. moving sense and location of limbs) inputs need to be integrated to assist executing reach-to-grasp movement. These sensations support generates motor program and correct movement trajectory. In this study, children with autism seems to integrate limited sensory inputs with learned motor program ineffectively due to poor awareness of moving sense in limbs (Baranek et al. 2005; Huebner and Lane 2001). As opposed to Glazebrook et al.'s (2009) finding that ASD took less MT without visual information during manual aiming, autistic group in this study appeared larger NJS and MU which indicate that poorer motor coordination and more impaired motor control without visual information, it is consistent with Molloy et al.'s finding Molloy et al. (2003) that autism whose postural control becomes poorer without visual information. Derived from literature, cerebellum plays an important role in motor planning, coordination and motor learning, integrates sensory information and stores motor programs of various skills (Shumway-Cook and Woollacott 2001). The motor and sensory characteristics that demonstrated in present study may relate to the findings of abnormal cerebellum function in autism (Eigsti and Shapiro 2003; Huebner and Lane 2001). Desmurget et al. (2001) also suggested that parietal-cerebellar circuits were involved in reaching movements without visual feedback, and a less distributed cortical network depends more on cerebellar structures in simple reaching movements without visual guidance (Desmurget et al. 2001). It seems that the autistic individuals who show poor coordination and who are more influenced without visual feedback may relate to impaired cerebellar function, nevertheless, it need further research to confirm.

In conclusion, results in this study indicated that children with autism demonstrate deficits of motor coordination in performing higher accuracy tasks and the tasks without visual information, and thus may develop compensatory ways to prevent missing target during the process of reach-to-grasp movement.

Limitations

Only children with high cognitive functioning were recruited in this study. Although, the findings may not probably be generalize to low functioning ASD. The participants were asked to use a comfortable way to grasp an object rather than as fast as they can in this study. Notwithstanding that this may be the reason that results of PV were not consistent with the finding of autistic adults study (Glazebrook et al. 2006). Future study may address the executing speed as an operating factor.

In this study, only kinematic evidences were provided, kinetics measures (e.g. electromyography) and neurophysiology techniques (e.g. functional magnetic resonance imaging) are suggested for the future study to explore motor control and sensory processing issues in ASD.

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