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The reach-to-grasp movement in children with autism spectrum disorder

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Autism is associated with a wide and complex array of neurobehavioural symptoms. Examination of the motor system offers a particularly appealing method for studying autism by providing information about this syndrome that is relatively immune to experimental influence. In this article, we considered the relationship between possible movement disturbance and symptoms of autism and introduced an experimental model that may be useful for rehabilitation and diagnostic purposes: the reach-to-grasp movement. Research is reviewed that characterizes kinematically the reach-to-grasp movement in children with autism compared with age-matched 'controls'. Unlike the age-matched children, autistic children showed differences in movement planning and execution, supporting the view that movement disturbances may play a part in the phenomenon of autism.

Keywords: autism; reach-to-grasp; human; motor control; human development; movement disorders

1. AUTISM AND MOVEMENT

Autism is a developmental disorder of largely unknown etiology. It is characterized by abnormalities in language, social relationships and reactions to the environment (Happé & Frith 1996; Happé 1999). Despite autistic children having been described as delayed from a developmental perspective, little emphasis has been placed on the development of motor function, which has often been thought to be intact. However, a growing number of descriptions and observations indicate that this may not be the case (Damasio & Maurer 1978; Vilensky *et al.* 1981; Bauman 1992; Hallett *et al.* 1993; Manjiviona & Prior 1995; Hughes 1996; Teitelbaum *et al.* 1998; Brasić 1999; table 1).

As described by Bauman (1992), people with autism exhibit a large collection of motor symptoms. These include delays in the attainment of motor milestones, such as clumsiness (i.e. awkwardness and difficulty in carrying out organized movements and actions in parallel), hyperactivity and hand flapping. These signs are particularly evident in stressful and/or stimulating conditions.

Neurological 'soft signs' have also been observed, the most common being choreoform movement of extremities, poor balance, poor coordination and impaired finger–thumb opposition. Muscle tone and reflex abnormalities are also common. In particular, the persistence of newborn reflexes and increased or decreased muscle tone have been found in children with autism. In fact, as infants, many autistic children have been noted to stiffen when held, or have been described as hypotonic.

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One contribution of 14 to a Theme Issue 'Autism: mind and brain'.

Probably the most characteristic abnormal motor behaviour exhibited by people with autism is the repetitive and stereotypical movement of the body, limbs and fingers.

Of particular interest are the unusual gait patterns that have been linked to those observed for extrapyramidal motor disorders. These patterns include poorly coordinated limb movements and shortened steps, as well as 'toe walking'. For example, Damasio & Maurer (1978) and Vilensky *et al.* (1981) reported that autistic children between the ages of 3 and 10 years exhibited walking patterns similar to those observed for patients with Parkinson's disease (see also Woodward 2001). They walked more slowly and with shorter steps than non-autistic children. However, the existence of such a Parkinsonian-type disturbance is disputed by Hallett *et al.* (1993) who found normal gait velocities and step lengths in patients with autism. Nevertheless, they identified movement abnormalities such as a decreased range of motion of the ankle, slightly decreased knee flexion in early stance and gait irregularity. They thus proposed that this clinical picture is suggestive of a disturbance of the cerebellum. Other symptoms that may resemble extrapyramidal impairments include delays in the initiation, change or arrest of a motor sequence. Expressionless faces with little spontaneous movements were also described.

Poor performance of motor imitation tasks and the failure to use gestures for communicative purposes have been largely addressed (Smith & Bryson 1994). Several deficits have been proposed that aimed to explain how the learning of expressive gestures is negatively affected. Such deficits include: the lack of imitative skills, motor dyspraxia and basic perceptual and attentional impairments.

Leary & Hill (1996) have recently adopted a radical point of view about the presence of movement disturbance

Table 1. Summations of previously conducted research on the development of motor function in autistic children.

study authors	number of subjects	task	significant findings
Vilensky *et al.* (1981)	21 children with autism (ages 3.3–10.0), 15 normal children (ages 3.9–11.3), five non-autistic hyperactive-aggressive children (ages 5.1–13.1)	following an IQ test, to walk (barefoot, whilst wearing shorts) at their normal rate along a rubber track	Kinesiologic gait analysis revealed that the autistic patients had: (i) reduced stride lengths; (ii) increased stance times; (iii) increased hip flexion at 'toe-off'; and (iv) decreased knee extension and ankle dorsiflexion at ground contact. In many respects, the gait differences between the autistic and normal subjects resembled differences between the gaits of Parkinsonian patients and of normal adults. The results are compatible with the view that the autistic syndrome may be associated with specific dysfunction of the motor system affecting, among other structures, the basal ganglia.
Hallett *et al.* (1993)	five adults with autism (four male, one female; ages 25–38), five healthy, age-matched controls (three male, two female; ages 25–36)	following an IQ test, to walk (barefoot, whilst wearing shorts) at a self-determined pace	Clinical assessment showed mild clumsiness in four patients and upper limb posturing during walking in three patients. The velocity of gait, step length, cadence, step width, stance time and vertical ground reaction forces were normal in all patients. The only significant abnormality was a decreased range of motion of the ankle. Some patients exhibited slightly decreased knee flexion in early stance. Clinically, the gait appeared to be irregular in three patients, but the variability was not significantly increased.
Manjiviona & Prior (1995)	12 children with AS (ages 7–17), nine children with HFA (ages 10–15)	IQ test followed by assessments of manual dexterity (speed and accuracy of hand movements, eye–hand coordination, coordination of both hands for a single task), ball skills (aim and catch a ball using both hands) and balance (static ability to hold a position and dynamic ability to be able to make spatially precise movements slowly, and with control of momentum)	The two groups did not differ on either total or subscale impairment scores. The results offer no support for clumsiness as a diagnostically differentiating feature of these disorders.
Hughes (1996)	36 children with DSM-III-R (American Psychiatric Association 1987) diagnosis of autism (22 male, 14 female), 24 non-autistic children with moderate LDs (11 male, 13 female), 28 young, normally developing, controls (12 male, 16 female)	following assessment of non-verbal mental age the subjects were instructed to insert an (experimenter-specified) end of a wooden rod (painted half black, half white) within either a red or a blue (again experimenter-specified) disc (each with a central well) such that it stood upright	The results obtained make clear that even very simple activities, such as this, depend upon several different processes of 'executive control': anticipatory monitoring, adjustment of an act in response to external feedback and coordination of separate elements into a goal-directed sequence. The performance of the normally developing pre-schoolers indicates that significant gains in executive control occur between the ages of 2 and 4 years. The performances of the other two groups indicate that although the development of executive control is delayed in both clinical groups, subjects with autism show an independent and marked impairment in this domain.
Miyahara *et al.* (1997)	26 children with AS (22 male, four female; ages 6–15), 16 children with LD (14 male, two female; ages 6–15)	following an IQ test, tests consisting of eight subtests in three sections: manual dexterity (two manipulative tasks and one drawing or cutting task); ball skills (one throwing and one catching task); and balance skills (one static and two dynamic balance tasks)	No relationship was found between intellectual and motor function; both groups demonstrated a high incidence of motor delay on the total test scores. A statistically significant difference was found between the two groups only on the manual dexterity subscore. Although the difference between the AS and LD groups did not reach an alpha level of 0.05, one particularly noteworthy result was the poorer ball skills exhibited by the children with AS.
Teitelbaum *et al.* (1998)	17 autistic infants (subsequently diagnosed by conventional methods at *ca*. 3 years or older), 15 normal infants	no specific task. Videos of the autistic children (recorded when they were infants) and normal infants were used to compare their patterns of lying (prone and supine), righting from their back to their stomach, sitting, crawling, standing and walking	Disturbances of movement were clearly detected in the autistic infants at the age of four to six months, long before they had been diagnosed as autistic. Specifically, disturbances were revealed in the shape of the mouth and in some or all of the milestones of development, including, lying, righting, sitting, crawling and walking.

symptoms in individuals with autism. These authors provide an explanatory analysis of the bibliography on movement impairments in autism, based on the modified Rogers scale (i.e. a checklist of movement disturbance symptoms for individuals with developmental or psychiatric disorders). Their review lists several papers that describe movement disturbance in autism. Instead of dismissing these symptoms as peripheral to the syndrome, they propose that motor disorder symptoms may have a significant impact on the core characteristics of autism. In particular, their aim was to show how some of the socially referenced characteristics of autism might be based on neurological symptoms of movement disturbance. Following the categories adopted by the motor checklist, they grouped the symptoms into three levels of disturbance. The first includes disturbances of motor function, which affect posture, muscle tone, movements that normally accompany other actions, and extraneous, non-purposeful movements such as tics. The second category lists impairments in volitional movements (e.g. motor planning difficulties, repetitive spontaneous movements, language difficulties, etc.). The third level of motor disturbance affects overall behaviour and activity, and symptoms were considered to be pervasive, uncontrollable behaviours. It follows that it is possible to connect social descriptions such as 'a failure to cuddle', 'socially inappropriate gestures' and 'an indifference to affection' to neurological motor symptoms like 'abnormal posture and tone', 'dyskinesia' and 'marked underactivity'. The authors stress that the application of a social context to the observed behaviours may divert attention from an appreciation of the possible neurological explanations for the same behaviours. They propose that a shift in focus to a movement perspective may provide new insights, which could result in the development of useful tools for future diagnosis and rehabilitation. The specificity of movement disturbance may be of particular research interest with a view to addressing diagnostic issues. In fact, movement symptoms may define specific subgroups of the autism spectrum. If movement symptoms are found to be present in any individual with autism, this may lead to new ways of perceiving and addressing existing difficulties (Leary & Hill 1996).

Along these lines, Manjiviona & Prior (1995) and Miyahara *et al.* (1997) investigated the usefulness of motor impairment as a diagnostic feature aimed at differentiating groups within the autistic population. Both studies assessed motor clumsiness by administering behavioural tests that addressed both fine and gross motor skills (e.g. manual dexterity, ball skills and balance). Manjiviona & Prior (1995) tested the assumption that motor impairment differentiates people with AS from people with HFA. The DSM-IV (American Psychiatric Association 1994) classifies both disorders as PDDs[1]. As no significant group differences were found for any measure on the behavioural motor test that they adopted (TOMI-H), the notion of clumsiness as a distinctive diagnostic feature between AS and HFA was refuted. For the sake of our discussion, the interesting finding of this study is that half of the subjects in both groups exhibited motor impairments and low-level performances when compared with normative data. In particular, children who exhibit motor impairment are not likely to have an isolated symptom, but show more pervasive movement disturbances that affect both fine and gross motor skills.

Miyahara *et al.* (1997) administered a standardized test of movement impairment, movement—ABC, which is a revision of the TOMI-H used by Manjiviona & Prior (1995), to both AS children and to children with LDs. This test assesses manual dexterity, ball skills and balance (as did the test employed by Manjiviona & Prior (1995)). They found a higher rate of AS children with motor incoordination (85%) than did Manjiviona and Prior (50%). Even though not directly explored by the author, the subscores obtained by AS subjects and the LD children for each subcategory on the movement test were almost identical. These results may provide further support for the hypothesis of a general, pervasive motor impairment in people with PDD, as proposed by Manjiviona & Prior (1995). Both studies sustain the need for future research to clarify the pattern of motor impairments within the autistic spectrum disorders, its specificity to the syndrome and its possible utility in the diagnosis and characterization of the syndrome itself.

A recent paper about motor control in autism addresses planning problems (Hughes 1996). The author administers a simple 'reach, grasp and place' task, which encourages a particular hand posture. The task leads to either comfortable or awkward final hand positions depending upon the subjects' planning abilities. Subjects with autism were significantly more likely to return their hand to an uncomfortable position. This result allows us to conclude that autistic children exhibit planning deficits for simple goal-directed sequences.

In line with the idea of using natural, non-arbitrary action sequencing to investigate a possible impairment in goal-directed activity in autism, the research described here is aimed at assessing one of the major motor milestones in the development of children, the reach-to-grasp movement. The reasons why the reach-to-grasp movement can be considered a motor milestone are various. For example, the high degree of development of the hand is paralleled by the development of a remarkable neural apparatus. The amount of cortical surface devoted to innervation of the hand testifies to its functional importance. This includes not only the large areas devoted to the hand in primary somatosensory and motor cortices, but also in the posterior parietal cortex and the premotor cortex. Further, it requires the coordination and the parallel processing of information streams concerned with *where* and *what* an object is together with *how* to deal with it.

In the following sections, we shall first describe the main kinematical features of the adult reach-to-grasp movement with particular emphasis on kinematic scaling with respect to object size and distance. We shall then describe the behavioural steps that underlie the development of a mature reach-to-grasp action. Next, we shall compare the reach-to-grasp pattern observed in autistic children with that of age-matched non-autistic children. Finally, we shall highlight features of the autistic reach-to-grasp kinematics, which may allow a (previously unidentified) association between IQ level and movement disorders in autism to be made.

2. THE REACH-TO-GRASP MOVEMENT

The reach-to-grasp movement is performed normally and routinely within the familiar context of living

activities. It is also a movement that has been well characterized experimentally (reviewed in Bennett & Castiello 1994). In particular, this experimental model has been used to characterize disturbances in various neurologically compromised populations and at different age levels, including infants and children (Bennett & Castiello 1994).

The everyday action of reaching to grasp an object is commonly described in terms of a proximodistal distinction. The reaching and positioning actions, affected by upper arm and forearm musculature, are subserved by central nervous system visuomotor mechanisms that are largely independent from mechanisms subserving the grasping action, i.e. hand opening and subsequent closing (upon the object). With this description, the two neural channels, reaching and grasping, are said to be activated simultaneously and in parallel (the 'channel' hypothesis of Jeannerod (1981, 1984)), being coupled functionally for the goal-directed action by a higher-order coordinative structure (Jeannerod 1981, 1984). The 'reaching' channel is said to extract information about the spatial location of the object for transformation into motor patterns that bring the hand appropriately towards the object. The 'grasp' channel extracts information about the intrinsic properties of the object (such as size and shape) for the determination of a suitable grasping pattern.

Many behavioural studies of the kinematics of the human reach-to-grasp movement have tested the hypothesis that the two modules, reaching and grasping, are implemented through separate neural channels (Marteniuk *et al.* 1990; Gentilucci *et al.* 1991; Jakobson & Goodale 1992; Castiello 1996). An approach common to many of these studies is that of attempting to choose experimental conditions that exert effects upon only one visuomotor channel. However, although the two components can be considered as distinct, they seem to be coupled functionally. Hence, although arm reaching serves the function of bringing the hand to the target object, and because therefore it may be postulated that its neural channel will be primarily affected by changing the object's spatial location, the object's size will also modify this component. For example, the peak velocity of the reaching arm is generally lower and the duration of its deceleration time longer for objects that are perceived to require greater precision (i.e. small and/or delicate etc.) than for objects requiring less precise handling (reviewed in Weir (1994)). Similarly, although hand posture serves the function of grasping the target object, and because therefore it may be postulated that its neural channel will be primarily affected by changing the object's size, the object's spatial location will also modify this component. For example, the time of maximum grip aperture is generally earlier for objects that are positioned near to the subject than for those positioned further away (Weir 1994).

Figure 1 depicts some kinematic features of the reach-to-grasp action that are sensitive to object size and distance. For the reaching component, these features are movement duration, the velocity amplitudes with which the movement unfolds and the time from peak velocity to the end of the movement (deceleration time). In particular, movement duration is longer, the amplitude of peak velocity is lower and deceleration time is more prolonged for smaller than for larger stimuli and for far than near stimuli (e.g. Gentilucci *et al.* 1991).

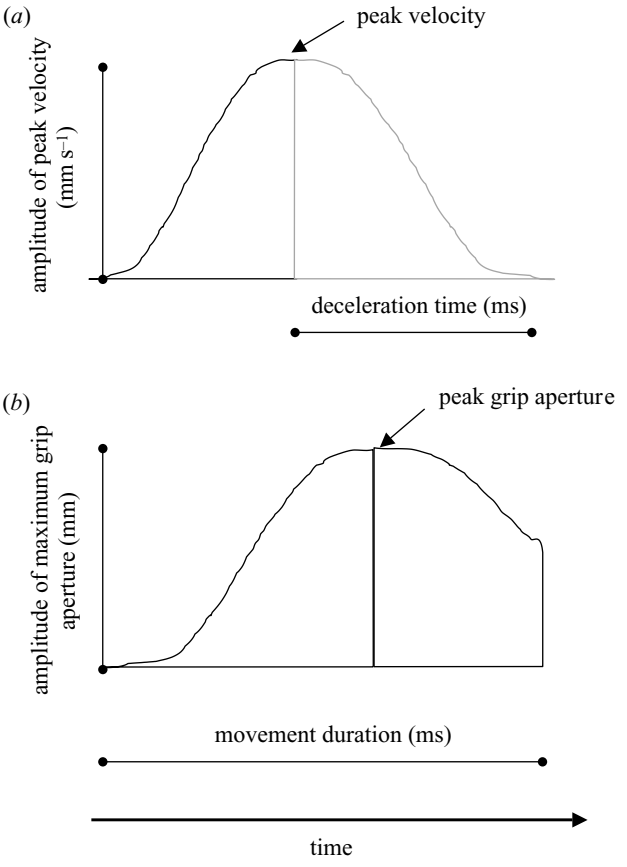

Figure 1. A graphical description of the kinematical variables analysed. Grey lines indicate the deceleration phase of the movement.

For the grasping component, these landmarks are the amplitude and the time of maximum grip aperture. In particular, the amplitude of maximum grip aperture is lower and it is reached earlier for smaller than for larger stimuli and for far than for near stimuli (e.g. Gentilucci, *et al.* 1991). As can be seen in § 3, these parameters play a key part during the development of a mature reach-to-grasp pattern.

3. THE DEVELOPMENT OF THE REACH-TO-GRASP MOVEMENT

In humans, reaching and grasping movements are not present at birth. Their development occurs as a series of steps during ontogeny. Reaching serves to bring the hand to a desired location in space. Thus grasping objects requires appropriate goal-directed reaching. Grasping involves digit coordination according to the intrinsic properties of the object (e.g. size and shape). Newborn infants do not grasp the objects they reach for. As observed in some of the newborn reflexes, as the arm extends forward, the hand has a tendency to open, and conversely, as the arm is flexed towards the body, the hand has a tendency to close (von Hofsten 1984). It is at around two months of age that the synergy described above begins to break up. von Hofsten (1984) found that, instead of opening the hand during the extension of the arm, two-month-old infants typically fisted the hand in the extended phase of the arm movement. At around three months of age, the infants started to open the hand again when

extending the arm, but this time only when fixating upon a target. The significance of this change lies in the fact that the opening of the hand can no longer be described simply as a part of an extension synergy, but as a preparation for grasping the object. At approximately four to five months of age, both the distance and the direction of the reach improve, but the hand orientation and finger closure are still rather limited.

It is by nine months of age that the hand begins to be shaped according to object size. von Hofsten & Rönnqvist (1988) monitored the distance between the thumb and index finger in reaches performed by five- to six-month-old, nine-month-old and 13-month-old infants. They found that the infants in the two older age groups did adjust the opening of the hand to the size of the target, but this was not evident for the youngest age group. The reason for this difference is that infants of five to six months of age do not predominantly use the thumb and the index finger when grasping objects, but the medial part of the hand and the palm. Further, although the older infants would adjust the opening of the hand to the size of the object, their pattern is still very different from the adult pattern where the hand fully opened during the approach to targets of different sizes (von Hofsten & Rönnqvist 1988). A possible interpretation of this behaviour is that a fully opened hand optimizes the possibility of grasping the object if the movement is not spatially precise.

The natural question is, therefore, when do children start to exhibit correct hand-preshaping (as a function of time and amplitude) with respect to object size and distance? Unfortunately, while the kinematics of the reach-to-grasp movement have been widely investigated in adults, and to some extent in infants, there are not many data available for the intermediate age level. Some evidence, however, is provided by Kuhtz-Buschbeck *et al.* (1998), who studied the kinematics of the reach-to-grasp action in children of 6 to 7 years of age, and from our pilot study (Mari *et al.* 1999) where children ranging from 8 to 12 years of age were tested. These children typically showed a patterning (with respect to object size and distance) that was similar to that of adults. These results are particularly relevant given that they provide a baseline for the comparison with autistic children of similar ages described in the following section.

4. THE REACH-TO-GRASP MOVEMENT IN AUTISTIC CHILDREN

Our investigation of the reach-to-grasp movement in autistic children relies on kinematic measures (Mari *et al.* 1999)[2]. We used a three-dimensional kinematic system to compare the reach-to-grasp movements of autistic children and age-matched 'controls'.

Given reports of awkwardness and difficulty in planning actions, together with the common finding of problems when executing goal-directed actions, it was hypothesized that the movement of children with autism might not show appropriate scaling for the size and distance functions. The choice of object size enables the manipulation of accuracy planning, a small object requiring a more precise grasp (precision grip) than a large object (whole-hand prehension). The choice of object distance enables assessment of the ability to scale appropriately the reaching velocity and acceleration for near and far objects. Further, based on reports stating that autistic children show difficulty in the activation of movement components (reviewed in Leary & Hill 1996), it is also hypothesized that a lack of coordination between the individual components might characterize the 'autistic' reach-to-grasp synergy. We tested 20 participants with either ASD or AS. Children were assessed for movement disorders that are common in a population with developmental disabilities and that would confound any interpretation of the results (e.g. tics, tremors and cerebral palsy). The children with such movement disorders and developmental disabilities were excluded from the study group ($n = 2$). Individual characteristics are shown in table 2. IQ was measured with the Weschler intelligence scale for children (WISC-R). The score for 10 of the autistic children was in the range of 70–79 and we labelled these children as 'low ability'. The IQ score for six of the autistic children was in the range of 80–89 and we labelled the children in this group as 'average ability'. The IQ score for the remaining four autistic children was in the range of 90–109 and we labelled these children as 'high ability'. We also tested 20 sex- and age-matched 'control' participants who reported no neurological or skeletomotor dysfunctions and were assessed to have an IQ in the normal range.

Figure 2 represents the experimental set-up and the stimuli used by Mari *et al.* (1999) and for collecting the data presented here. The participant was seated in a height-adjustable chair such that their feet and back were supported, and their forearms rested on the table surface (see figure 2*a*). The starting position of the arm and hand to be observed (either right or left, dependent upon the handedness of the participant), was with the shoulder slightly flexed and internally rotated (*ca*. 45°), the elbow flexed (*ca*. 90°), the forearm in mid-pronation and the ulnar border of the hand resting upon a yellow pad 10 cm anterior to the thorax. The thumb and index finger were held in a relaxed position of opposition. The objects to be grasped were highly translucent blocks of clear Perspex (see figure 2*a*) that were either small (1 cm × 1 cm × 1 cm) or large (4 cm × 4 cm × 4 cm) in size (independent variable = object size) and positioned vertically in the midline at either 18 cm or 28 cm (independent variable = object distance) from the starting position. Computer-controlled LEDs embedded within the working surface were used to illuminate the objects. Three LEDs were placed below the large object and one LED was placed below the small one (see figure 2*c*,*d*, respectively). The number of LEDs illuminated depended upon the object in question. Upon the illumination of an object, the participant was required to reach towards and then grasp and lift it. A specific movement speed was not stipulated, but each participant was instructed to perform the movement as they would normally do when reaching to grasp an object at home. The experiment lasted *ca*. 30 minutes and comprised about 60 reaches divided into four blocks. Pauses were allowed between the blocks to avoid fatigue. For each target size/distance combination, the participants performed five practice trials and then a block of 10 'real' trials. To distribute practice effects across conditions (size and distance), the block order was counterbalanced across participants.

Table 2. Characteristics of the autistic and 'control' subjects.

autistic group							control group			
subject	diagnosis	age	sex	hand	IQ range	IQ score	subject	age	sex	hand
1	ASD	11.3	M	RH	low ability	(70–79)	21	11	F	RH
2	ASD	9.3	M	LH	low ability	(70–79)	22	12.1	M	LH
3	AS	12.7	M	RH	low ability	(70–79)	23	10.4	M	RH
4	ASD	10.2	F	LH	low ability	(70–79)	24	10.2	M	RH
5	AS	10	F	RH	low ability	(70–79)	25	10	F	RH
6	AS	12.3	F	RH	low ability	(70–79)	26	12	F	RH
7	ASD	12.1	M	RH	low ability	(70–79)	27	12.5	M	RH
8	AS	9.6	M	RH	low ability	(70–79)	28	10	M	RH
9	ASD	10	F	RH	low ability	(70–79)	29	10	F	RH
10	ASD	12	F	RH	low ability	(70–79)	30	11.8	F	RH
11	ASD	9.6	F	RH	average ability	(80–89)	31	11.7	F	RH
12	AS	10.1	M	RH	average ability	(80–89)	32	8.9	M	RH
13	AS	9	M	RH	average ability	(80–89)	33	8.8	M	RH
14	AS	12.3	M	LH	average ability	(80–89)	34	12	M	LH
15	AS	11	F	RH	average ability	(80–89)	35	11	F	RH
16	ASD	9	F	RH	average ability	(80–89)	36	9.4	F	RH
17	ASD	9.8	M	RH	high ability	(90–109)	37	8	F	RH
18	ASD	13.1	F	RH	high ability	(90–109)	38	8.5	M	RH
19	ASD	7.4	M	RH	high ability	(90–109)	39	8.9	M	RH
20	ASD	9.5	M	RH	high ability	(90–109)	40	11.5	F	RH

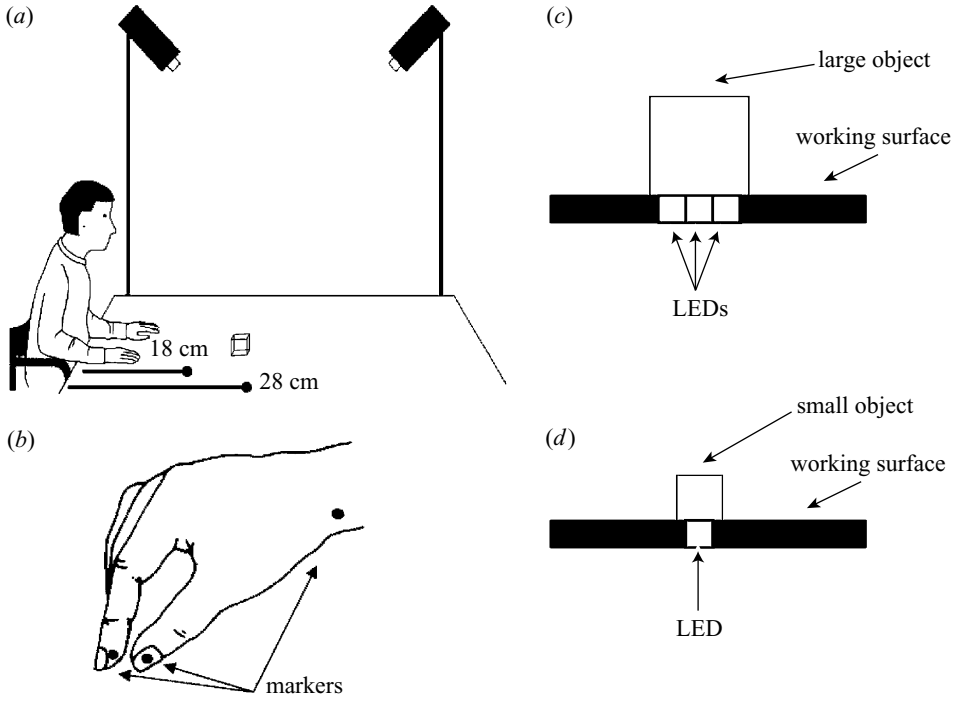

Figure 2. A schematic depiction of the experimental set-up. (*a*) The position of the subject and the two ELITE cameras. (*b*) The three marker positions. (*c*), (*d*) The method by which the target objects were illuminated.

Movements were recorded using an ELITE motion analysis system, which consisted of two infrared cameras (sampling rate 100 Hz) inclined at an angle of 30° to the vertical and placed 2 m from the side of the table and 2 m apart (see figure 2*a*). These recorded the reflections of passive markers (0.25 cm diameter) attached to the following points of either the right or left upper limb (again dependent upon the handedness of the participant): (i) the wrist–radial aspect of the distal styloid process of the radius; (ii) the index finger–radial side of the nail; and (iii) the thumb–ulnar side of the nail (see figure 2*b*). Each experiment was also recorded on videotape. The polar orientation of each subject (and the table, which was able to rotate) was dependent upon their handedness, thus allowing the (fixed-position) cameras to have the same relative perspective of all subjects.

The reaching component was assessed by analysing the trajectory and velocity profiles of the wrist marker. The grasping component was assessed by analysing the distance between the thumb and index finger markers as a

function of time. Movement duration was calculated as the time between movement onset (defined as the time at which the wrist first began to move) and the end of the action (defined as the time at which the index finger and thumb closed upon the target and there was no further change in the distance between them). The period following this, during which the target was lifted, was not assessed. The dependent variables were chosen on the basis of having demonstrated size and distance functions in previous research (Jakobson & Goodale 1992; see figure 1). The difference between the onset of the reaching component (as defined above) and the onset of the grasping component (defined as the time at which the index finger and thumb first began to open), i.e. the onset 'delay', was also calculated. For each participant in the two groups, mean values for each of the dependent measures were calculated for each size/distance combination. An ANOVA has been conducted with 'group' as the between-subjects factor (autistic and 'control') and 'object size' (small, large) and 'object distance' (near, far) as within-subjects factors. Prior to the ANOVA, normal distribution of the data was verified. Post-hoc comparisons were performed with the Newman–Keuls procedure (alpha level = 0.05).

A global view of the results obtained by comparing the 20 autistic children with the 20 'control' children indicates that the autistic children show a generalized slowness that, as explained in the following section, has to be ascribed to the autistic children belonging to the 'low ability' group. Apart from this, the disorder appears to have little influence on the size and distance functions addressed in this study. In general, the results obtained for both the autistic and 'control' participants mirrored those from previous studies of adults and children (Gentilucci *et al.* 1991; Jakobson & Goodale 1992; Castiello 1996; Kuhtz-Buschbeck *et al.* 1998). Autistic children were thus able to regulate these measured movement parameters correctly. The manipulation of object size and distance had predictable effects on the reaching and grasping components for the two groups. Consistent results within the reach-to-grasp literature reveal a longer movement duration, a prolonged arm deceleration time and a lower amplitude of arm peak velocity for smaller than for larger stimuli and for near than for far stimuli. Further, they reveal that the amplitude of maximum grip aperture is usually lower and it occurs earlier for smaller than for larger stimuli (Marteniuk *et al.* 1990; Gentilucci *et al.* 1991; Jakobson & Goodale 1992; Castiello 1996). As shown in table 3, movement duration for the two groups was longer for the small than for the large object and for the objects positioned at the far than at the near distance. The peak velocity was higher and occurred earlier for the large than for the small object and for objects positioned at the greater distance. The time from peak velocity to the end of the movement (deceleration time) was longer for the small than for the large object and for the objects positioned at the far than at the near distance. For the grasping component, autistic children showed neither a greater proportional opening of the hand nor a larger absolute hand opening than that found for the 'control' group. For both groups, the timing of the peak aperture was earlier for the small than for the large object and for the objects positioned at the near than at the far distance.

In addition, the autistic children exhibited no inability to activate the required and appropriate motor components. Further, this study illustrates that autistic participants showed that the timing of the peak hand opening changing as a function of movement duration demonstrates how aspects of one component are sensitive to changes in the other (Gentilucci *et al.* 1991). The autistic children showed no dysfunction in this sensitivity. The overall form of the motor programme of autistic participants thus appears to be maintained. The selection of muscles and the timing of their activation enable the correct relative timing of all movement parameters of the reach-to-grasp components. A suitable number of neuronal sets are mobilized and the temporal arrangement of these sets is maintained.

Despite this patterning remaining intact, the following section highlights several differences between the autistic groups that may serve as a first step towards identifying specific areas that are worthy of future investigation.

5. THE RELATIONSHIP BETWEEN IQ AND MOVEMENT PATTERNING

As judged from examination of the video recordings, the movements of the autistic children with IQs indicating 'low ability' were substantially different from those of the autistic children with 'high' and 'average' ability (for examples of these movements please refer to www.pc.rhbnc.ac.uk/staff/ucastiello/autism.html). The results presented below refer to the comparison between the 'low ability' autistic children, the 'average/high ability' autistic children and the 'control' children (see table 2). The children belonging to the 'high ability' and the 'average ability' groups were grouped together because preliminary analyses showed no difference in their respective performances. To examine possible differences in the kinematics, an ANOVA with 'group' ('low ability', 'average/high ability' and 'control') as a between-subjects factor and 'object size' (small, large) and 'object distance' (near, far) as within-subjects factors was conducted.

A question of interest associated with the autistic syndrome is whether motor assessment alone is able to provide a means of differentiating objectively between the putative subgroups. The kinematical assessment of the present study reveals differences between the 'average/high ability' and 'low ability' autistic subjects. Interestingly, the main difference between the two groups lies in the speeds with which the movement unfolds. As shown in figure 3*a–d*, both movement duration and deceleration time were significantly longer, the amplitude of peak velocity was significantly lower, and the time of maximum grip aperture was significantly later for the 'low ability' group than for the other two groups. For the 'average/high ability' group, both movement duration and deceleration time were significantly shorter, the amplitude of peak velocity was higher and the time of maximum grip aperture was reached earlier than for the other two groups. For the same parameters, the 'control' group showed intermediate values.

The slowness of the 'low ability' group shows a strong resemblance to Parkinsonian-type bradykinesia. The parallelism between autistic and Parkinsonian movement has already been proposed by a few authors who found abnor-

Table 3. Kinematic parameters for the autistic and 'control' groups with respect to object size (small, large) and distance (near, far), and statistical values for the main factors group, size and distance; s.d. (standard deviation) in parentheses.

	kinematic parameters				statistical values	
	autistic group		control group			
size function	small	large	small	large	main factor group	main factor size
movement duration (ms)	1010 (427)	900 (347)	845 (84)	786 (84)	$F_{(1,19)} = 20.01$, $p < 0.0001$	$F_{(1,19)} = 46.21$, $p < 0.0001$
deceleration time (ms)	623 (289)	520 (173)	532 (64)	476 (54)	$F_{(1,19)} = 37.45$, $p < 0.0001$	$F_{(1,19)} = 24.11$, $p < 0.0001$
amplitude of peak velocity (mm s^{-1})	600 (187)	681 (133)	638 (76)	732 (76)	$F_{(1,19)} = 28.41$, $p < 0.0001$	$F_{(1,19)} = 33.87$, $p < 0.0001$
time of maximum grip aperture (ms)	625 (308)	700 (295)	405 (61)	473 (58)	$F_{(1,19)} = 76.32$, $p < 0.0001$	$F_{(1,19)} = 42.25$, $p < 0.0001$
amplitude of maximum grip aperture (mm)	41 (5)	75 (4)	41 (4)	75 (5)	n.s.	$F_{(1,19)} = 56.52$, $p < 0.0001$
distance function	near	far	near	far	main factor group	main factor distance
movement duration (ms)	867 (301)	952 (282)	777 (100)	848 (121)	$F_{(1,19)} = 58.32$, $p < 0.0001$	$F_{(1,19)} = 53.49$, $p < 0.0001$
deceleration time (ms)	549 (195)	645 (240)	467 (65)	543 (71)	$F_{(1,19)} = 41.06$, $p < 0.0001$	$F_{(1,19)} = 35.72$, $p < 0.0001$
amplitude of peak velocity (mm s^{-1})	603 (175)	707 (226)	655 (78)	754 (86)	$F_{(1,19)} = 17.31$, $p < 0.0001$	$F_{(1,19)} = 40.31$, $p < 0.0001$
time of maximum grip aperture (ms)	609 (290)	680 (195)	400 (54)	482 (60)	$F_{(1,19)} = 63.25$, $p < 0.0001$	$F_{(1,19)} = 46.37$, $p < 0.0001$
amplitude of maximum grip aperture (mm)	61 (5)	60 (6)	59 (6)	60 (5)	n.s.	n.s.

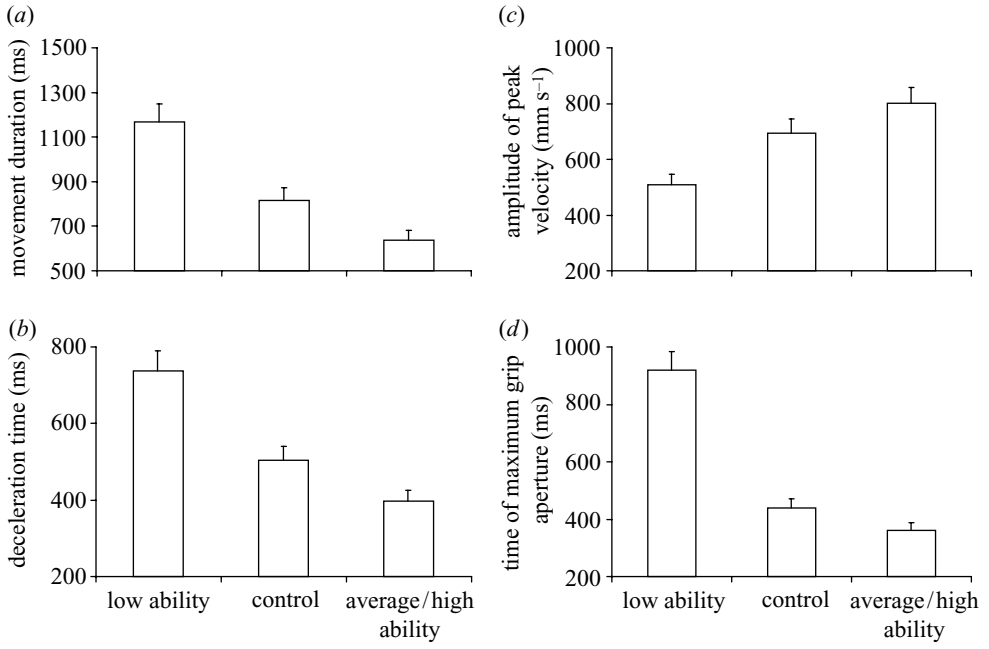

Figure 3. A graphical representation of the differences between the 'low ability', 'average/high ability' and 'control' groups for the parameters: (*a*) movement duration; (*b*) deceleration time; (*c*) amplitude of peak velocity; and (*d*) time of maximum grip aperture, collapsed for object size and distance. Error bars reflect the standard error.

malities in gait (Vilensky *et al.* 1981; Hallett *et al.* 1993; Teitelbaum *et al.* 1998).

The slowness with which the autistic 'low ability' group unfolds the kinematic patterning of the reach-to-grasp action seems similar to the Parkinsonian-type pattern (Castiello *et al.* 1994). Although the performance was

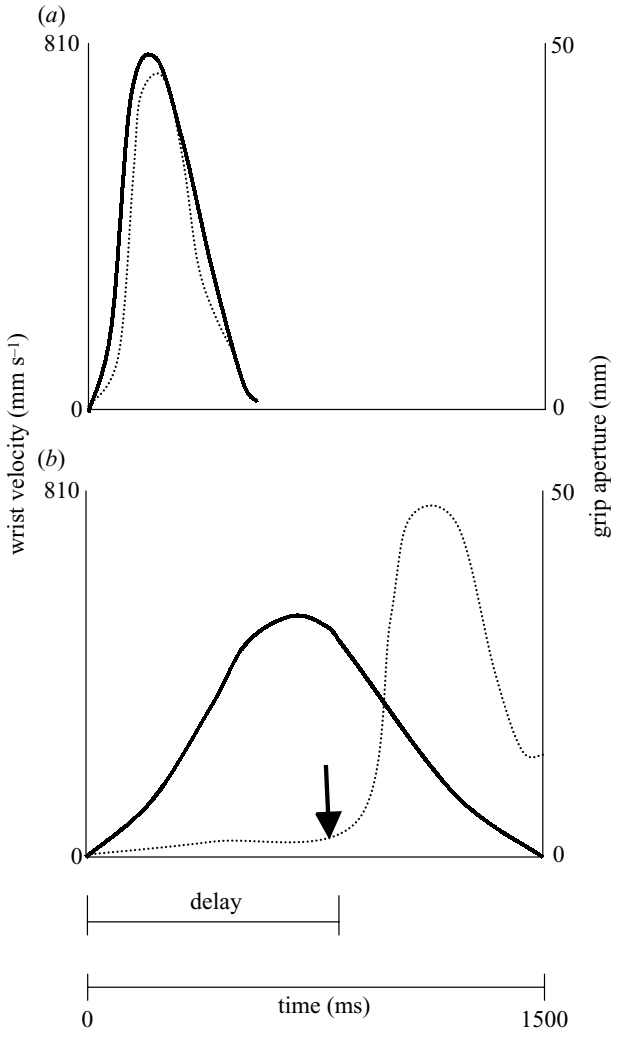

Figure 4. A graphical illustration of the onset 'delay' measured for (*a*) 'average/high ability' and (*b*) 'low ability' groups. Solid line, wrist velocity; dotted line, grip aperture. The arrow indicates the onset of finger opening with respect to the onset of arm movement, as measured from the wrist velocity profile.

slow, there were no deficits in the 'low ability' groups' ability to modify the spatiotemporal characteristics of the reach-to-grasp pattern in response to experimentally imposed changes in either the distance of the object from the subject and/or the size of the object. The 'low ability' autistic participants were thus deemed able to regulate the movement parameters correctly. For the participants of this group, however, it was the relative activations of the reach and grasp components that revealed abnormalities: the onset of the grasp component was delayed with respect to the onset of the reaching component ($F_{(2,18)} = 21.06$, $p < 0.0001$; figure 4). The 'low ability' autistic children, as already found for Parkinson's disease patients (Castiello *et al.* 1994), were not able to initiate the two components in a near-simultaneous manner. As depicted in figure 4, the 'low ability' autistic children show a difference when the onset time of the grasping component is compared with that of the reaching component. For the 'average/high ability' group, the onset of grasping occurred, on average, 110 ms after the onset of the reaching. By contrast, the 'low ability' group began grasping, on average, 802 ms after reaching. This result could be attributed to the slower movement duration measured for the 'low ability' group. However, to give additional confirmation of this result, the onset of grasping was expressed as a percentage of movement duration. The opening of the index finger and thumb thus began at 72% of movement duration for the 'low ability' group, but at only 15% for the 'average/high ability' group ($F_{(2,18)} = 41.32$, $p < 0.0001$). A regression analysis was performed comparing the onset of grasping (using both absolute and relative values) and movement duration. The fact that no correlations were found indicates that the later onset of grasping measured for the 'low ability' group was not due to a relationship between movement duration and grasping onset. However, despite the fact that the bradykinesia and the delayed finger opening seem to be independent effects, it might well be that both of them could result from a generally low speed of information processing. An interesting feature of this delay in the onset of grasping found for the 'low ability' group is the difference in grasping times measured for the small and the large objects (interaction group by size, $F_{(2,18)} = 9.32$, $p < 0.001$, $p_s < 0.05$). For this group, grasping began, on average, 812 ms after reaching when a movement towards the small object was performed. However, when reaching for the large object, grasping began, on average, 748 ms after reaching. For the 'average/high ability' group, the parameter delay was similar for both the small and the large objects (110 ms and 112 ms, respectively). Further, as a result of this delay, it was found that the grip opening and closing phases exhibited by the 'low ability' participants were performed much faster than for the other groups.

These results might indicate that the near-concurrent activation of the reach and grasp components is desynchronized by a specific impairment in the management of synchronous motor programmes in the 'low ability' autistic participants. Theoretically, this result is interesting since several researchers have attributed the deficit in the initiation of motor sequences and the poor coordination of separate elements into a goal-directed sequence to the autistic syndrome (reviewed in Leary & Hill (1996) and Hughes (1996)). This delay in the near-concurrent activation of the two components could also reflect the dysfunction in autistic children of the central mechanisms that process the superimposition of the two motor programmes. In the case of the reach-to-grasp movement, the control channels for reaching are most probably distinct from those required for manipulation (Jeannerod 1984). Thus, the deficit in the 'low ability' autistic children applies to the simultaneous activation of motor programmes that are largely independent, but show functional coordination. Interestingly, the delay between the activation of the two components is related to the size of the object to be grasped. With the more accurate precision task (i.e. reaching-to-grasp the small object), 'low ability' autistic children show a greater delay than for the more gross type of grasp (i.e. reaching-to-grasp the large object). This adds support for a central neural processing origin for the lag in activation of the distal motor pattern. This 'dysfunction' may be more pronounced in the performance of more precise tasks that require more complex neural programming, i.e. a greater problem for less cognitively able children.

In contrast to the 'low ability' autistic group, the children of the 'average/high ability' autistic group seem to adopt a strategy that might be the product of a feed-forward system that defines both the initial state of the limb and the ultimate goal, and then determines a movement towards the appropriate target location. The very rapid actions executed by this group indicate that once the action planning has been finalized, it must be performed very quickly to avoid any disruptive feedback mechanisms. In this regard, Masterton & Biederman (1983) indicated that children with autism were unable to visually control reaching movements very efficiently. Hence, the pattern exhibited by the 'average/high ability' autistic children might be related to the difficulties experienced when attempting to use external feedback to guide behaviour. Further, we add to this conclusion by suggesting that this deficiency may be different with respect to different autistic groups. Another possible explanation is that the children of the 'average/high ability' group demonstrate both hyperagility and hyperdexterity, being thus able to unfold the reach-to-grasp pattern very quickly and efficiently.

6. CONCLUSION

In conclusion, our findings support the view that movement disturbances may play an intrinsic part in the phenomenon of autism, that they are present during childhood and that they can be used to subdivide autism into specific groups. Further, given that the reach-to-grasp movement is one of the major motor milestones in child development, it might well be that movement analysis could be used as an early indicator of potential autism.

On the basis the of evidence provided above, it can thus be suggested that differences in the reach-to-grasp patterning exhibited by autistic people confirm their dysfunctioning ability to initiate, switch, efficiently perform or continue any ongoing action including those involved in communicating, interacting socially or performing useful daily living activities. Consequently, it follows that a shift in focus to a movement perspective may reveal a new route for investigating autistic behaviour that might be useful for rehabilitation and diagnostic purposes.

The autistic and 'control' subjects who participated in this study are gratefully acknowledged. Dr Claudia Bonfiglioli and Dr James Taylor are thanked for helping with various aspects of this research.

ENDNOTES

[1]This classification is no longer inherent in the APA DSM-IV, although it was in previous editions and when the Manjiviona & Prior study was conducted.

[2]This reference is concerned with an abstract publication describing data from only 10 of the 20 autistic children presented here.

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GLOSSARY

AS: Asperger syndrome
ASD: autism spectrum disorder
DSM: diagnostic and statistical manual
HFA: high-functioning autism
IQ: intelligence quotient
LD: learning disability
LED: light-emitting diode
PDD: pervasive developmental disorder
TOMI-H: test of motor impairment—Henderson revision