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RESEARCH ARTICLE

Planning actions in autism

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Abstract It has been suggested that the deficit in understanding others' intention in autism depends on a malfunctioning of the mirror system. This malfunction could be due either to a deficit of the basic mirror mechanism or to a disorganization of chained action organization on which the mirror understanding of others' intention is based. Here we tested this last hypothesis investigating the kinematics of intentional actions. Children with autism and typically developing children (TD) were asked to execute two actions consisting each of three motor acts: the first was identical in both actions while the last varied for its difficulty. The result showed that, unlike in TD children, in children with autism the kinematics of the first motor act was not modulated by the task difficulty. This finding strongly supports the notion that children with autism have a deficit in chaining motor acts into a global action.

Keywords Autism · Motor acts · Action planning · Mirror neuron system

Introduction

The present study was prompted by a recent experiment in which the EMG activity of the myloioideus muscle (MH), a muscle involved in mouth opening, was recorded in typically developing (TD) and children with autism during an action in which they were required to reach and grasp a piece of food and bring it to the mouth (Cattaneo et al. 2007).

The data showed that, in TD children, the EMG activity of MH muscle started to increase several hundred milliseconds before the participant's hand grasped the food, continued to increase during food grasping, and reached its peak when the participant started to open the mouth. These findings indicate that TD children when start an action, have clear from the very beginning of the action, not only its final goal, but also how to implement it motorically. The motor behavior of children with autism was strikingly different. In these children no activity increase of MH muscle was found during reaching and grasping phases of the action. The MH muscle became active only during the final bringing-food-to-the-mouth phase.

How can these findings be interpreted? From the mere fact that children with autism brought the food to their mouths, it is clear that they had the intention to perform the action. However, this intention was not reflected in their motor organization. Children with autism knew their own intention but appeared to be unable to translate it into an appropriate motor sequence.

The muscle activation observed in TD children is, most likely, the external manifestation of the chained neural organization of motor acts described by Fogassi et al. (2005). These authors recorded neurons discharging in association with grasping movements from the inferior parietal lobule (IPL) of monkeys. The animals were tested in two experimental conditions. In the first, they had to grasp an object in order to place it into a container; in the second they had to grasp a piece of food to eat it. The initial motor acts, reaching and grasping, were identical in the two conditions, while the last one, that determining

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the goal of the action, was different. The results showed that most IPL neurons ('action-constrained' motor neurons) discharged selectively when the monkey grasped an object or a piece of food for a specific final goal, for example grasping-for-eating. Most interestingly, some of these 'action-constrained' motor neurons had mirror properties and selectively discharged during the observation of grasping embedded in a given action (e.g., grasping-for-eating but not grasping-for-placing). This property represents a simple, but very interesting, mechanism that allows individuals to recognize not only the 'what' of an observed motor act (grasping), but also the 'why' of it (e.g. grasping-for-eating) that is the intentions of the agent.

Let us go back to the motor behavior of children with autism we described above. Why do they activate so late the MH muscle? Is it a problem of putting together single motor acts into an action? How is this difficulty reflected in the action kinematics?

In order to answer these questions, we carried out an experiment in which the first two motor acts of two actions were the same in term of type of object to be grasped and object distance from the agent, while the last one differed for its execution difficulty. The experiment was based on previous kinematics studies that showed that when individuals program an action formed by several motor acts, the motor act kinematics is influenced by factors such as action final goal and the context in which the action is carried out. Thus, if the first motor acts are identical but the last one varies, its effect should influence the execution of the first ones.

Early evidence for this interaction was reported by Marteniuk et al. (1987). These authors explored the determinants of the movement kinematics by comparing grasping movements in two different situations. In both of them, the individuals had to grasp an object, but in one situation they had to throw the object in a large container, while in the other, they had to place it into a small container. The data showed that the act of grasping an object was slower when the individuals had to place it into the small container than when they had to throw it away.

More recently, Johnson-Frey et al. (2004) examined whether manipulating the intentions of the agent regarding forthcoming actions, influences the time course and kinematics of visually guided reaching-to-grasp movements. Volunteers performed two-steps motor act sequences where the initial motor act always involved reaching for and grasping cubes located at a constant distance. Demands of the second motor act were systematically manipulated. The results showed that, although the object and spatial parameters (cube size and distance) remained constant across conditions, the duration of the initial movement differed substantially, depending on the actions individuals intended to perform once the objects were in hand. Specifically, the time to execute the first motor act increased when the difficulty of the second one increased.

In the present experiment, we adopted a paradigm similar to that of Johnson-Frey et al. (2004) in order to assess the influence of the demands of the task on motor behavior of children with autism and to find out whether children with autism are able to assemble different motor acts into a coherent action.

Methods

Participants

We tested a group of 12 children diagnosed with ASD (11 males and 1 female, mean age: 10.00 ± 2.3) and a group of 14 TD children (8 males and 6 females, mean age: 7.6 ± 2.1). Children with ASD were recruited in a Center of Pediatric Neuropsychiatry (Empoli "ASL 11") and in a Center of Autism ("ASL", Reggio Emilia). The diagnosis was made by means of the Autism Diagnostic Observation Schedule (ADOS) (Lord et al. 2005). Scores from 7 to 10 indicate autistic spectrum disorder and scores from 10 and above indicate autism. The mean ADOS total score (Module 3) was 13.75 (SD 3). ASD children had an IQ > 70, calculated with the Italian version of the Wechsler Intelligence Scale for Children-Revised (WISC-R) Rubini and Padovani (1986). The mean IQ was 84.25 (SD 11.3). The group of TD children was matched to the group of children with ASD for non-verbal cognitive level, tested by Raven's Progressive Matrices (Raven 1984). The Raven's Progressive Matrices scores of the two groups of participants were compared using unpaired t-tests. The Raven scores were not different between the two groups ($P = 0.59$). All procedures were approved by the local ethical committee and all participants and/or their parents gave informed written consent.

Procedure

Participants sat in front of a table where there were a starting button, a touch sensitive plate and a container (Fig. 1). All trials started with the children's right hand resting on the start button. The children were required to reach with the right hand for a metal object positioned on the plate, to grasp it and to place it into a container positioned on the right side of the plate. The container could be of two types, a small one (a square 2.5×2.5 cm) or a large one (a square 6.5×6.5 cm). The two containers were randomly changed in different trials by the experimenter. Thus, children performed two actions that differed only for the size of the container into which the object was dropped. The two actions

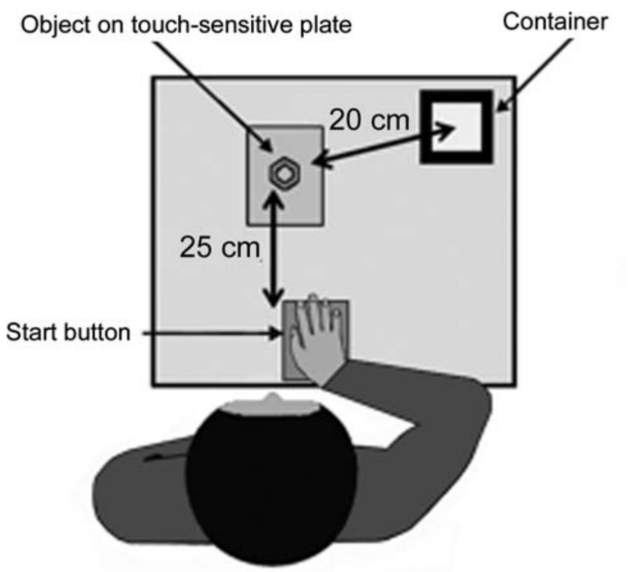

Fig. 1 Schematic representation of the experimental setting. The child sat with the *right hand* resting on the starting button and was required to pick up a metal object from the plate and to drop it into a container, that was alternatively large or small, according to a pseudo-random order. The starting button and the plate were connected to a electrical circuit. The distances between the elements were kept constant for all participants and were of 25 cm between the button and the plate and 20 cm between the plate and the container

were repeated 20 times each in a pseudo-random order with an inter-trial interval of 10 s. A pair of thin copper plates placed on the children's fingers were connected to a 5 V circuit that signaled the contact of the fingers with the metal object. The staring button signaled the beginning of movement (T1). The finger sensors signaled the contact with the object (T2) and the time when it was dropped into the container (T4). The plate signaled the lifting of the object from its support (T3). The variables that were considered for analysis were the reaching-time calculated as T2-T1 and the time for placing the object into the container, calculated as T4-T3.

Trials were discarded for analysis when the participants did not make a good contact with the touch sensitive plate or with the object. The rate of discarded trials was 8% among TD children and 10% in ASD children ($P = 0.36$).

Statistical analysis

The study was designed for repeated measures between groups, with a 2 × 2 structure. The two factors were: (a) Action type (two levels: small container, large container) and (b) Action phase (two levels: reaching and placing). The variable was the movement time. A corresponding between-groups ANOVA was performed. Post hoc analyses were made with Neuman–Keuls' test.

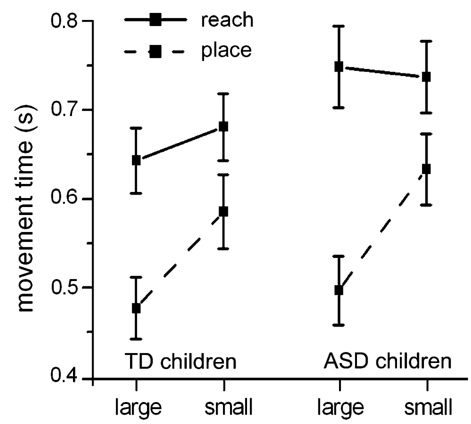

Fig. 2 Mean values of movement times in the two groups of children in the two phases (*reach* and *place*) of the two actions (placing in the *large* or *small* containers)

Results

The results of the experiment are shown in Fig. 2. The continuous line shows the movement time required to reach the object (T2-T1), the dashed line shows the movement time between grasping the object and dropping it into the containers (placing, T4-T3). The ANOVA showed a significant overall interaction between Group (ASD, TD children), Action type (small, large container) and the Action phase (reach, placing) ($F(1, 24) = 4.4712$, $P < 0.5$). The post hoc analysis showed that in TD children both reach time and the placing time were significantly different in the two actions ($P < 0.005$ and $P < 0.001$). In contrast, in ASD children the placing time ($P < 0.001$), but not the reach time ($P = 0.54$), differed between the two actions. No Group effect, nor any other interaction involving the Group factor was found significant. This shows that neither the overall movement time nor the single movement phases were different between ASD and TD children, in any of the two actions.

Discussion

The present study shows that, in TD children, the difficulty of the final motor act in an action formed by a sequence of motor acts, influences the movement time of the first one in spite of the fact that this act was identical in the two actions studied. More specifically, although the size of the object and its distance from the hand were the same, the reaching time increased with the difficulties of the final motor act. These results are in accord with previous studies (Marteniuk et al. 1987; Johnson-Frey et al. 2004) in adults and indicate that TD children, like healthy adults, plan a visually determined action globally, rather than a sequence of independent steps.

In every day life, one often has to choose among different motor plans, and select one in particular to fulfill his/her intentions. This selection is most likely determined by the activity of the prefrontal lobe that selects the appropriate motor plans (Fuster 2002; Tanji and Hoshi 2008). Here when we speak of action global planning we mean a mechanism concerning the internal organization of a single action, subsequent to prefrontal selection of possible actions for a specific goal achievement. This organization mechanism is most likely located in the parietal lobe and carried out by action-constrained neurons (Fogassi et al. 2005).

Most importantly, the present study shows that, in contrast to TD children, children with autism are unable to translate their motor intention into an action, but program single motor acts independently one from another.

A fundamental aspect of autistic syndrome consists in deficits in social interaction and interpersonal communication (Kanner 1943). Some time ago, it has been proposed that a malfunctioning of the mirror system underlies this deficit. This hypothesis, originally advanced by Williams et al. (2001) on the basis of theoretical considerations, has recently found empirical support. Electroencephalographic studies showed that cortical rhythms, recorded from the central (motor) cortical region, which in TD children desynchronize during both the execution and the observation of hand movements (Altschuler et al. 1997; Hari et al. 1998; Cochin et al. 1999), in children with autism, desynchronize only during hand movement execution (Oberman et al. 2005; Martineau et al. 2008). The absence of motor cortex activation during the observation of movements done by others indicates a deficit of mirror system. The view that children with autism have an impairment of the mirror system received further support from brain imaging data showing that the observation and imitation of emotional expressions determine a weaker activation in the mirror system in children with autism than in TD children. Most interestingly, the bold signal reduction was found to correlate with the severity of autism (Dapretto et al. 2006). Further evidence in favor of a functional deficit of the mirror system in autism came from MEG and TMS experiment (Nishitani et al. 2004; Théoret et al. 2005).

The conclusion from these data was that the mirror neuron system is impaired in autism and this impairment prevents children with autism to understand others. The recent discovery of chained organization of executed and observed motor acts enlarged the concept of mirror mechanism (Fogassi et al. 2005, see also Introduction). These data showed that in addition to a mechanism based on mirror neurons that describes a motor act as a such (grasping, reaching, etc.), there is a more complex mechanism based on 'action constrained' mirror neurons that code not only what the observer sees, but also the action that the agent intends to do, that is the agent's intention.

At this point the issue rises of what may be the mirror deficit in autism. Is it the basic mirror neuron mechanism that is impaired? Or is the 'actions constrained' mirror neuron organization that is underdeveloped? The present study provides evidence in support for this last hypothesis: Children with autism were unable to organize their motor actions, as a chain of motor acts. This deficit, obviously, cannot depend on a malfunctioning of the mirror neurons. In contrast, the demonstration that the basic motor structure responsible for action organization is impaired supports the idea that its use for understanding actions done by others also should be impaired.

A further argument in favor of the idea that at a basis of the autism is an impairment of the chained organization of the motor system comes from a recent experiment in which TD children and children with autism were tested with pictures representing motor acts (Boria et al. 2008). The presented motor acts were either a hand touching an object or a hand grasping an object in different ways. Children were asked to tell the experimenter what the agent was doing (i.e. grasping or touching) and, in the case of grasping, why the agent was doing that action (for using it or for moving/placing it). The results showed that the children with autism have no difficulties in recognizing the motor acts (touching or grasping) (see for similar results Hamilton et al. 2007), but frequently failed, in contrast to TD children, in understanding the intention behind the motor act. Since the understanding of the motor act is exactly what the mirror neurons do, these data suggest that the basic mirror neuron system is not impaired, or at least, is not markedly impaired, in autism.

It is interesting to note that there is a clear parallelism between the motor and cognitive deficits shown by children with autism. This is nicely illustrated by the results of the present experiment. The time of the last motor act of the two actions was influenced by its difficulty, indicating that children with autism obey motor laws, the Fitts' law specifically in this case. In other terms, their organization of motor acts appears to be intact, as normal is their capacity to understand motor acts done by others. In contrast, the time of the first motor act was not influenced by action complexity. This incapacity to translate their intention into a motor chain leading to the action goal appears to parallel their incapacity to understand the intention of others on the basis of their motor behavior. Motor and cognitive deficit coincide.

Finally, it should be made clear that the two possible hypotheses concerning the deficit in mirror system in autism discussed above are not mutually exclusive. The data present in this study and those of Cattaneo et al. (2007) strongly suggest that a deficit in the chained organization of the motor system is the major responsible of autistic deficit in understanding others. This does not exclude, however, that in autism there is also a decrease in the number or the efficacy of mirror neurons. In favor of this possibility are recent EEG data showing that the lack of desynchronization in children with autism during the observation of movements done by others is only present when the agent is a stranger. In contrast, when the child observes movements done by a familiar person, or observes a movie showing his own movements, the cortical motor rhythms do desynchronize (Oberman et al. 2008). This suggests that in autism also the basic mirror system is impaired but only partially and not in such a dramatic way to prevent motor act understanding.

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