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Using movement kinematics to understand the motor side of Autism Spectrum Disorder

by

Jessica Podda

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Prof. Cristina Becchio	Supervisor
Examining Board:	
Dr. Tommaso Brischetto Costa	External examiner
Dr. Spencer Hayes	External examiner
Dr. Luca Turella	External examiner

Dibris

Department of Informatics, Bioengineering, Robotics and Systems Engineering

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Contents

Chapter 1

General Introduction

“I have no intention of reading this book, but I like how soft the cover is”, “He took the phone, but he had no intention of calling the doctor” or even “How do I know his intentions?” are just commonly used expressions, which reveal the key role played by intentions in everyday life. A crucial component for successful interactions between humans is the ability to understand other’s intentions behind an observed behavior. Since a consistent number of research findings indicates that intentions do leave ‘tangible’ traces in the movement kinematics, becoming available in a person’s behavior, the current hypothesis is that the ability to understand others’ intentions from movements is unlikely to be separated from the capability to detect key movement kinematics.

Clinical and experimental evidence claims that individuals with Autism Spectrum Disorder (ASD) experience difficulties in understanding and responding appropriately to others. Beside core deficits in social interaction and communication, atypical motor patterns as well widespread difficulties in perception of biological motion have been often reported in people with ASD. It has been speculated that a part of these sensorimotor atypicalities could be better explained considering prospective motor control (i.e., the ability to plan actions toward future events or consider future task demands), which has been recently hypothesized to be crucial for higher mind functions (e.g., understand intentions of other people). However, current support is mixed and puzzling potentially because no common pattern characterizes individuals with autism homogeneously.

Given the importance of movements for acquiring knowledge about the external world and people, the current dissertation aimed to use movement kinematics as a tool for exploring the ‘motor’ side of ASD. Before examining experimental data (Chapters 2-4), in the next paragraphs I present an overview of the studies which tried to shed light on motor impairments often reported for ASD individuals within the intention understanding from movement framework.

1.1 When movements speak louder than words: the ‘motor’ side of autism

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder defined by persistent deficits in social communication and social interaction across contexts, not accounted for by general developmental delays and restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association 2013). Atypical social interaction, including a reduced sharing of interests and emotions with other people, lack of initiation of social interaction, deficits in use of non-verbal communicative behaviors, such as impairments in social use of eye contact, as well as failure to develop and maintain peer relationships, are deficits typically associated to ASD people.

Beside these core symptoms, evidence indicates that individuals with ASD often exhibit impairments in vestibular control, gross and fine motor coordination, oculomotor functions and action planning abilities (Fournier et al. 2010). Although not primary considered a diagnostic feature, these sensorimotor impairments, first described by Kanner (1943), have been increasingly acknowledged as widespread in ASD, and have been shown to significantly impact the quality of life (Gowen and Hamilton 2013; Trevarthen and Delafield-Butt 2013).

Motor abnormalities in ASD can be observed in infancy (Ozonoff et al. 2015; Provost et al. 2007; Teitelbaum et al. 1998) and persist throughout childhood and into adulthood (Fournier et al. 2010; Van Waelvelde et al. 2007). Although they can be detected early in infancy between 12 and 14 months of age (Zwaigenbaum et al. 2013) and reliably diagnosed by 24 months of age (Charman and Baird 2002), the average age at diagnosis is between 4 and 7 years (Mazurek et al. 2018). While retrospective research has generated important insights to current early detection strategies (Costanzo et al. 2015; Esposito et al. 2009; Teitelbaum et al. 1998), there are some limitations inherent in such study designs (e.g., potential recency effect and sampling biases from parental reports about early symptoms and home-videos, respectively). To overcome these limits, over the past several years, prospective research designs have been increasingly integrated by experimental measures (e.g., eye tracking, evoked brain responses, motion capture techniques), yielding additional insights regarding underlying developmental processes as well as potential biomarkers that might ultimately contribute to early detection (Zwaigenbaum et al. 2013). Moreover, impaired motor skills in ASD also emerge on common standardized tests, such as Bruininks–Oseretsky Test of Motor Proficiency (BOT-2; Bruininks and Bruininks 2005) and Movement Assessment Battery for Children (M-ABC-2; Henderson et al. 2007).

The recent research has consistently found that infants and children with ASD experience both gross and fine motor delays, and/or atypical motor patterns, suggesting a possible underlying problem with movement kinematics patterns (Gowen and Hamilton 2013; Mostofsky et al. 2009; Rinehart, Bellgrove, et al. 2006).

Studies investigating gross motor skills in autistic children and adults highlighted abnormalities in trunk posture and balance (Kohen-raz et al. 1992), in step width, step and stride length (Rinehart, Tonge, et al. 2006) as well a marked loss of smoothness (Nobile et al. 2011) and dysrhythmia (Jansiewicz et al. 2006). Moreover, a high incidence of toe walking in children with autism is often reported (Barrow et al. 2011).

Paradigms exploring fine motor skills revealed important differences between ASD individuals and typically developing peers. Handwriting difficulties are widespread (Kushki et al. 2011). Overall legibility, which refers to ‘recognizability’ of handwriting, is often impaired in children with ASD. For instance, one specific component of legibility, namely letter formation, which reflects the quality of letters and includes factors such as shape distortions, reversals, and rotations, is marked atypical. Common form errors reported in children with ASD include the use of sharp edges in place of smooth corners, and larger than typical letter extensions (Fuentes et al. 2009). Additionally, some aspects of reach-to-grasp movements appeared to be different in ASD such as slower and more jerky movements (Crippa et al. 2015; Fabbri-Destro et al. 2009; Forti et al. 2011).

In everyday life people adjust their behavior in anticipation of what they plan to do next (e.g., to grasp a bottle to drink or to pass it to another person). Hence, in a provocative way, onward movements can be said to reveal future state of an action sequence. It has been speculated that a great part of motor atypicalities in ASD could be explained taking into account of *prospective sensorimotor control*, which allows to accurately organize actions considering forthcoming acts and their consequences (Rosenbaum et al. 2012). Disturbance of primary prospective motor control has been proposed to contribute to deficits in higher mind functions of individuals with ASD (Cavallo et al. 2018), including action prediction, understanding others' mental states, imitation and the development of positive social attitudes (Cook 2016). For instance, a recent report based on retrospective analysis of family home videos on feeding indicates that atypical anticipation of actions is a precursor of autism (Brisson et al. 2012). The results show that 4-months-old children, who later received a diagnosis of ASD, anticipate less often the arrival of the spoon to their mouth in a feeding situation than do children who are not at risk (von Hofsten and Rosander 2012).

However, it is unclear which level of motor control may be impaired in ASD. Low level sensory input information (e.g., tactile, visual, proprioception) seems to be the same or even improved in autism, while integration of different sensory signals is often reduced (Gowen and Hamilton 2013). Experimental evidence suggests that children with ASD may differ from typically developing children in the efficiency of the organization of single motor acts into an entire sequence of action (Mari et al. 2003; Trevarthen and Delafield-Butt 2013) (for a detailed description of processes involved in motor control see the review by Gowen and Hamilton 2013). Yet, results are quite puzzling. For example, while some authors observed that autistic children were more likely to end their movements in an awkward posture, suggesting that they did not take the end position into account when planning their movements (Hughes 1996), others found that children with ASD altered their initial grasp in anticipation of the final motor step in a similar degree to age-matched control children (van Swieten et al. 2010). In a well-known study, Cattaneo and colleagues (2007) asked a group of typically developing children and a group of children with ASD to perform reach-to-grasp movements with two different prior-intentions (i.e., grasp a food to eat or to place it into a container). The electromyographic (EMG) activity of the mylohyoid muscle (MH), a muscle involved in mouth opening, was recorded and defined as an index of prospective motor control. Authors found that, in typically developing children, the MH activation began well before the hand had grasped the piece of food to take it to the mouth. In contrast, in children with ASD, this activation started only when the to-be-grasped food was already traveling toward their mouth, demonstrating a failure in action chaining. This lack of anticipation was also evident when children were required to observe an experimenter perform the reach-to-grasp-to-eat action. In typically developing group, the activation of the MH muscle started as soon as the reaching movement began, much before the object was grasped. In children with ASD, the MH muscle activation appeared only much later (i.e., approximately when they started bringing food to the mouth).

This was in line with a follow-up study by Fabbri-Destro and co-workers (2009). They explored action chaining mechanism in autistic children who were required to grasp an object and place it inside either a small or large container. While in typically developing children, the initial reach to the object was slower when the target container was smaller, denoting that the difficulty of the final action goal was early programmed into the entire movement sequence, autistic children showed no difference in movement duration between the two container sizes. Notably, they found that only the time of the last motor act of the two actions was influenced by its difficulty (i.e., small container vs. large container), indicating that children with autism obey to fundamental motor law as their typically developing peers did. Taken together these findings suggest that the effort to translate their intention into a motor chain early leading to the action goal may parallel their difficult to understand the intention of others on the basis of their motor behavior.

Awareness of others' intentions requires prospective control in terms of an anticipation of forthcoming acts, and this is apparent in how infants take part to conversation with their mother and/or to play activities with peers. Failure to time movements prospectively and meet expectation in movement will impede efficient goal acquisition and frustrate a sense of success, causing negative emotions of self-protection and avoidance (Delafield-Butt and Trevarthen 2017). In this direction, Boria and colleagues (2009) explored ASD children's ability to understand the goal and the prior-intention of motor actions in an action observation task. Results indicated that children with ASD were able to understand the 'what' of a motor act (e.g., grasping a pair of scissors), but they were impaired in understanding the 'why' of it (e.g., grasping a pair of scissors to use it). This deficit was present, however, only when they have to rely exclusively on the agent's motor behavior, but not when children were provided with additional information nearby the object.

Since consistent evidence supports the strong link between action execution and action perception, it has been hypothesized that atypical movement execution may parallel problems with the perception of biological motion in individuals with ASD. In line with this, Cook and colleagues (2013) examined the relationship between movement kinematics and action perception in high-functioning autism through a motion-tracking technology. They demonstrated that high-functioning adults with autism performed more jerky movements than control adults when required to perform sinusoidal movement with their right arm. Results showed that the more atypical an autistic participants' kinematics, the less likely they were to classify observed biological movements as 'natural'. In addition, authors found that the degree to which kinematics were atypical was correlated with a bias towards perceiving biological motion as 'unnatural' and with the severity of autism symptoms as measured by the ADOS (Lord et al. 1999). Furthermore, this result is consistent with recent evidence showing that altered movement kinematics in autism, which could lead to an atypical movement representation, is likely to impact on the perception, prediction and understanding the action of others (Brewer et al. 2016).

To date, problems with perceiving and categorizing biological motion in autism have been reported from the age of 2 years (Klin et al. 2009) through to adulthood (Blake et al. 2003; Cook 2016) and the neural response to biological motion differs between individuals with autism and control participants as reported using electroencephalography (Oberman et al. 2005), magnetoencephalography (Nishitani et al. 2004) and fMRI (Freitag et al. 2008). For example, Oberman and colleagues (2005) found that the lack of suppression of mu wave during action observation suggests a possible dysfunction in the mirror neuron system, involved in many of the behavioral deficits observed in individuals with ASD. Indeed, it is well documented that individuals with ASD show deep difficulties in those processes supported by mirror neuron system, such as, for instance, relating to others cognitively and emotionally, and imitating their actions (Oberman et al. 2005). Similarly, using fMRI, Martineau and colleagues (2010) showed atypical activation in high functioning young adults with autism during observation of human movement in various cerebral areas, including the motor cortex, the IFG, and the parietal lobule. However, Cusack and colleagues (2015) did not find any differences between ASD and TD participants in processing various aspect of biological motion (e.g., from the basic ability to distinguish biological from non-biological motion to the capacity to discriminate a dancing action from a fighting action). Indeed, findings suggested that autistic individuals were able to detect biological motion for interpreting other people’s actions adequately. However, they fail to use this ability adequately during real-life social interactions (Cusack et al. 2015).

The discovery of mirror neurons in ventral premotor area F5 and inferior parietal lobule of monkey brain (Di Pellegrino et al. 1992) and the so-called mirror neuron system (MNS) in the human brain, a network involving ventral premotor and posterior parietal cortices (Rizzolatti et al. 1996), has led to an amplified interest in the neural mechanisms underlying cognitive and social skills. Since one of the core functions of mirror neurons in the human brain was related to both the imitation of human actions (Iacoboni et al. 1999) and inferences about goals or intentions underlying observed actions (Fogassi et al. 2008), early developmental failure of the MNS has been postulated to contribute to varied social-cognitive difficulties characteristic of ASD (Oberman et al. 2005).

Investigations into the neural underpinnings of action understanding have typically focused on two neural systems: the Action Observation Network (AON) and the Mentalizing Network (MZN). Both AON and MZN networks are involved in biological motion perception, understanding actions and attributing intentions, however they appear to be functionally and anatomically segregated, at least in some ways. AON includes the lateral dorsal and ventral premotor cortex (PMC) and inferior frontal gyrus (IFG), the inferior (IPL) and superior parietal lobules (SPL), intraparietal cortex, and along the postcentral gyrus and the superior and middle temporal gyri (Caspers et al. 2010). Some of these areas, specifically ventral premotor cortex and inferior parietal lobule, further correspond to those in MNS (Press 2011). Automatic imitation paradigms indicated that AON is biologically tuned, preferentially responding to the observation of biological stimuli, rather than non-biological stimuli (Brass et al. 2000; for a review see Press 2011). Moreover, it has been demonstrated that this network responds specifically to human biological motion that adheres to normal kinematic laws (e.g., the two-thirds power law of motion; Lacquaniti et al. 1983) (Casile et al. 2009). Given the hypothesis that one understands other's action by mapping those actions on to oneself motor system, deficits in this mapping thereby result in an inability to interpret the actions of others and respond appropriately. Some authors have suggested that the social impairments observed in individuals with autism stem from underlying deficits in the MNS (the 'Broken Mirror' Theory) (Ramachandran and Oberman 2006). Empirical evidence concerning the Broken Mirror Theory has produced highly mixed results, with as many studies reporting typical MNS structure and function in ASD (Fan et al. 2010; Hamilton et al. 2007; Pokorny et al. 2015) as those finding impairments (Cattaneo et al. 2007; Oberman et al. 2005).

The MZN consists of the medial prefrontal cortex (mPFC), posterior superior temporal sulcus (pSTS), temporoparietal junction (TPJ) and precuneus (Frith and Frith 2006). Recent evidence indicates that MZN may also affect the perception of biological stimuli. For instance, the ‘gating hypothesis’ predicts that observed stimuli thought to be biological gains privileged access to the AON (Roberts et al. 2014). Indeed, for example, Stanley and colleagues (2007) reported that during concurrent observation of orthogonal dot-motion displays, movement deviation, known as *motor contagion* (Blakemore and Frith 2005), was enhanced when participants were informed that the observed stimuli were human-generated compared to computer-generated (Stanley et al. 2007). MZN has mostly been studied within the context of the ‘Theory of Mind’, a mechanism which underlies a crucial aspect of social skills, i.e. being able to consider mental states, in terms of knowing that other people know, want, feel, or believe things (Baron-Cohen 1985). Similar to the Broken Mirror Theory, it has been proposed that deficits in the MZN may contribute to impairments in social cognition observed in people with autism (the ‘Mind-blindness Theory’) (Baron-Cohen 1985), such that autistic people may have difficulty interpreting the intentions of others. Studies examining function of the MZN have found altered activation in ASD participants compared to TD controls (Kana et al. 2014). However, the exact nature of this other’s intention ‘blindness’ is still matter of debate and the exact mechanism supporting intention understanding remains unclear.

1.2 Uncovering what is ‘covert’ through movement kinematics: a brief state of art

As descripted in the previous paragraph, current evidence consistently reported widespread sensorimotor difficulties in individuals with a diagnosis of ASD. For example, during mutual exchange between infant and parent, whereas typically developing babies react reciprocally to parent’s vocal and facial expressions and movements, children with autism fail to do so, possibly not understanding the ‘why’ of the parent’s gesture (Ansuini et al. 2016). What kind of intention information is actually available in the features of others' movements? How can we understand other individual's intention by simply observing his movement?

Recent evidence indicates that intentions do leave 'tangible' traces in the movement kinematics, becoming available in a person's motor behavior: how an action is performed is not solely determined by biomechanical constraints, but it depends largely on agent's intention, i.e., why the action is performed (Ansuini et al. 2014). This raises the possibility that intentions may become visible in a person's overt motor behavior (Runeson and Frykholm 1983). This was first demonstrated by Marteniuk and colleagues (1987) by asking participants to perform reach to grasp movements in order to either fit a disk or to throw it away. They found that participants altered their movements as a function of different action goals. Notably, participants showed longer deceleration time and lower hand peak velocity when required to fit than to throw the object. Since this pioneering work, a plethora of studies have used the reach to grasp movement as a special window into studying whether and how specific kinematic features modulate with respect to object size (see e.g., Ansuini et al. 2015; Ansuini et al. 2016; Flindall and Gonzalez 2013), shape (e.g., Santello and Soechting 1998; Schettino et al. 2003), and weight (e.g., Ansuini et al. 2016; Eastough and Edwards 2007) as well as to the agent's intention (Ansuini et al. 2015; Cavallo et al. 2016). Evidence that intentions affect not only reaching components, such as movement duration and wrist velocity, but also whole hand kinematics was further provided by Ansuini and colleagues (2006), who extrapolated angular excursion of all five fingers together with adduction/abduction angles using sensors embedded in a glove. Findings indicated that, although the to-be-grasped object was the same, different co-variation patterns among finger joint angles were observed depending on whether the task was to place the object in a tight or a large niche (Ansuini et al. 2006). The involvement of whole hand in kinematics modulation was confirmed by further studies. For example, evidence indicated that when the bottle was grasped with the intent to pour, both the middle and the ring fingers were more extended than for all the other actions

(Ansuini et al. 2008). Similarly, participants place their thumb and index finger in a higher position when they grasp the bottle with the intention to pour than when they grasp it with the intention to lift (Crajé et al. 2011). Furthermore, Ansuini and colleagues (2016) revealed that the index finger was less extended in the palmar direction (i.e., z-index) when participants were required to grasp a glass full of iron screws than when they were pretending to grasp it as if it was present in the scene. Additionally, using the same experimental window, kinematics modulation has been demonstrated for grasping movements performed with an individual intention and grasping movements preparing to a subsequent social interaction (e.g., Becchio et al. 2008, 2010, Ferri et al. 2010, 2011).

Since research findings pointed out that intention information is still present and available in movement kinematics, several studies investigated whether observers are able to extract and use this information to understand individuals' intentions. One helpful approach to explore the role of kinematics is the progressive temporal and/or spatial occlusion, which consists in manipulation of either the time course of movement information or the degree of visibility of selected spatial areas available to the observer, respectively (Abernethy and Russell 1987). A useful demonstration of this technique was provided in sport settings by Abernethy and colleagues (2008), who have demonstrated that expert participants, but not novices, are able to extract useful kinematic information in advance from their challenger's lower body movement pattern. But what specific kinematic cues did participants use to make their anticipations judgment? To examine the spatial locus of key kinematic features, Sartori and co-workers (2011), masking visibility to selected parts of agent's movement present in video-clips, found that arm and forearm kinematics were sufficient to discriminate between movements performed with different intentions. However, overlooking the potential role of other compensatory or alternative information, one limitation of this method is that this does not provide a direct means for determining the specific contribution of kinematics. This restriction was overcome by Manera and colleagues (2011) using the point-light technique, which entails disconnected points of light corresponding to the key joint centered on the body of the person being observed, in absence of contour, texture, shape, and color cues, while preserves essential kinematic information provided in the movement pattern of the agent (Johansson 1973; Vanrie and Verfaillie 2004). Results indicated that, even when no contextual information is available, kinematics may provide a sufficient basis for discriminating between different intentions and this was confirmed by further action observation studies (see e.g., Ansuini et al. 2015; Becchio et al. 2012; Cavallo et al. 2016; Podda et al. 2017).

1.3 The current research

The aim of the current dissertation is to tackle the motor ‘problem’ in ASD exploring whether and how prospective motor control may be atypical in children with a diagnosis of autism, given that actions are directed into the future and their control is based on knowledge of what is going to happen next (von Hofsten and Rosander 2012). To do this, I applied an integrative approach based on motion capture techniques, neuropsychological assessment and behavioral paradigms.

To explore whether children with ASD altered their initial grasp in anticipation of what they or their partner in action planned to do next with the object, a simple object manipulation task, in which a cylinder had to be moved from a table to a shelf of varying height, was implemented. Here, the grasp height effect was used as a ‘spatial’ index of prospective motor control (Chapter 2).

Given that an important aspect of prospective planning concerns the spatiotemporal patterning of an action sequence (e.g., when the hand starts to adjust to future acts), to study whether kinematic modulation in ASD differ depending on different self or other’s action plans, participants were asked to perform reach-to-grasp movements towards a bottle with different intentions. In contrast to traditional methods, a predictive multivariate machine learning based approach was utilized to probe the predictive power of movement kinematics in discriminating different self or other’s action plans over time (Chapter 3).

Recent studies indicated that observers are usually able to pick up and use this kinematic information to judge an agent’s intention simply observing his/her movement flow (Abernethy et al. 2008; Becchio et al. 2012; Manera et al. 2011; Podda et al. 2017; Sartori et al. 2011). Having established that intention information was available in observed motor patterns, ASD individuals’ ability to go beyond the ‘here and now’ of the action itself to read the intention behind the observed movements was tested in a yes/no task paradigm (Chapter 4).

Differences between sample size and age of participants, as well as their cognitive and motor development, make comparison across previous studies that investigated motor skills in ASD difficult. Studies presented in this dissertation tried to cope with these limitations in two ways. Firstly, unlike previous researches, typically developing and autistic participants were matched for chronological age, gender, stature, handedness, and FS IQ, as measured by WISC-IV (Wechsler 2003). Secondly, a set of neuropsychological tests to gather comprehensive overview about children’s language, motor and executive functions was administered. For the sake of clarity, I provided a detailed description of the neuropsychological assessment used in Appendix A.

Chapter 2

The Grasp Height in Autism [1]

2.1 Introduction

The ability to accurately anticipate and predict forthcoming actions and their effects is essential to solve daily sequential tasks, such as using a knife to spread jam on bread or grasping a bottle to pour a liquid without spilling it. A useful way to study this ability is to observe adaptations in one's behavior as a function of the behavior that follows. If an action differs depending on the subsequent action, then the anticipatory effect can be said to reflect prospective sensorimotor control (Ansuini et al. 2015; Rosenbaum et al. 2012).

Anticipatory changes of this sort have been studied extensively in object manipulation (Ansuini et al. 2006, 2008; Armbrüster and Spijkers 2006; Becchio et al. 2008, 2012; Cohen and Rosenbaum 2004; Crajé et al. 2011; Johnson-Frey et al. 2003; Marteniuk et al. 1987; Rosenbaum et al. 1990, 1993; Sartori et al. 2009; Schuboe et al. 2008). For example, it is already well known that individuals tend to grasp objects differently depending on what they plan to do with the objects (Ansuini et al. 2015). A clear demonstration of prospective sensorimotor control for object manipulation is provided by the grasp height effect, i.e., the tendency to take hold of objects at a height that is inversely related to the height of the target location that they are attempting to reach (Rosenbaum et al. 2012). For example, when placing a book on a shelf, the higher the shelf, the lower individuals tend to grasp the book. Doing so has been shown to promote not just comfort of the end posture (i.e., end-state comfort), but also better control at the time of task completion (Rosenbaum et al. 2006). Thus, the initial grip of the

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[1] The study presented here is part of the paper published as: Ansuini, C., Podda, J., Battaglia, F. M., Veneselli, E., & Becchio, C. (2018). One hand, two hands, two people: Prospective sensorimotor control in children with autism. *Developmental cognitive neuroscience*, 29. doi: 10.1016/j.dcn.2017.02.009

book reflects an anticipation of the posture the body will be in once the target location of the action is reached.

Behaviors that reflect this effect have been reported when adult participants were required to handle an object to move it to a target position with only one hand (unimanual object manipulation; Cohen and Rosenbaum 2004; Rosenbaum and Jorgensen 1992; Weigelt et al. 2007) as well as when they had to use both hands to grasp two bars simultaneously or were free to choose the hand (bimanual object manipulation; Haggard 1998; Janssen and Steenbergen 2011; Meyer et al. 2013; Rosenbaum et al., 1990). Furthermore, there is evidence of grasp height effect in typically developing children from 7 to 12 years of age, with an increase of the effect as their age develops within this range (Janssen and Steenbergen 2011; van Swieten et al. 2010).

A far less studied aspect of prospective sensorimotor control is the planning of cooperative actions with others. Acting jointly with another person requires one to consider and integrate not only one’s own but also their partner’s next action (Sebanz et al. 2006). Consider, for example, one person handing books to another when filling a bookshelf together. Formalizing this example, Meyer and colleagues (2013) found that adult participants modulated the choice of the grasp height to accommodate not only their own end-state but also their action partner’s end-state. Moreover, several studies indicated that a prospective control of others action may appear in healthy young children, who are able to flexibly adjust their grasping behavior to accommodate to their action partner (see e.g., Jovanovic and Schwarzer 2017; Knudsen et al. 2012; Meyer et al. 2016). This result has been taken to signify similarity in mechanisms underlying prospective control of individual and joint action sequences. However, the exact mechanism supporting joint action planning remains unclear. Do individuals represent their action partner’s discomfort and therefore adjust their own actions accordingly? If so, does joint action planning depend on the ability to represent others’ internal states? More broadly, does it relate to social functioning? Abnormalities in social functions are a striking feature of autism, a neurodevelopmental disorder defined by characteristic deficits in social interaction and communication, so-called social symptoms. Even individuals with autism spectrum disorder exhibit deficits in coordinating gaze and action with others and under-standing the mental states and social intentions of other people (Happé and Frith 2014). Yet, this condition is also defined by a less well-researched range of non-social motor symptoms (Cook 2016; Fournier et al. 2010), including impairments in basic motor control (Adrien et al. 1993; Jansiewicz et al. 2006; Teitelbaum et al. 1998), difficulties performing skilled motor gestures (Mostofsky et al. 2006), abnormal patterns of motor learning (Haswell et al. 2009), and disturbances in the reach-to-grasp movement (Mari et al. 2003; Noterdaeme et al. 2002). Comparison between the performance of typically developing children and children with autism spectrum disorders may thus inform us about the link between prospective sensorimotor control, motor skills, and more complex socio-cognitive skills.

With this in mind, in the present study, we examined prospective planning for self and other people's actions in typically developing children and children with autism spectrum disorder without accompanying intellectual impairment using the height at which the cylinder was grasped (i.e., grasp height) as a continuous measure for prospective sensorimotor control across tasks.

2.2 Materials and methods

2.2.1 Participants

Seventeen children with Autism Spectrum Disorder without accompanying intellectual impairment (ASD group: 15 males) and 20 typically developing children (TD group: 16 males) took part to this experiment. Children from both groups were recruited from the Child Neuropsychiatry Unit of the 'Giannina Gaslini' Hospital and schools in Genova. All participants had normal or corrected-to-normal vision and were screened for exclusion criteria (dyslexia, epilepsy, and any other neurological or psychiatric conditions). All participants in the ASD group were diagnosed according to DSM-5

(American Psychiatric Association 2013). The Autism Diagnostic Observation Scale (ADOS- 2; Lord et al. 2012) and the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al. 2003) were administered by two skilled professionals (a child neuropsychiatrist and a neuropsychologist). All participants met the cut-off criteria for ASD with respect to the total ADOS-2 score and the communication and reciprocal social interaction subscales (see Table 2.1 in Appendix B for details). Groups were matched for age (ASD M ± SD = 9.9 ± 1.6 years. months; TD M ± SD = 9.5 ± 1.5 years. months; t35 = .804, $p > 0.05$), gender (ASD M:F = 15:17; TD M:F = 16:20), stature (ASD M ± SD = 141.2 ± 8.7; TD M ± SD = 138 ± 9.1 cm; t35 = 1.177, $p > 0.05$), and Full Scale IQ (FS-IQ) as measured by the Wechsler Scale of Intelligence (WISC IV; Wechsler 2003) (ASD M ± SD = 96.3 ± 10.2; TD M ± SD = 102.8 ± 9.4; t35 = - 2.020, $p > 0.05$) (see Table 2.2 in Appendix B for details). All but two of the participants (one in the ASD group and one in the TD group) were right-handed according to the Edinburgh Handedness Inventory (Oldfield 1971). Every child was tested on the following motor and cognitive tests: The Movement Assessment Battery for Children (MABC-2; Henderson et al. 2007), the Tower of London (TOL; Anderson et al. 1996), and the Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn and Dunn 1997). Total MABC-2 score was significantly lower in the ASD group compared to the TD group (ASD M = 15.35 vs. TD = M 31.85; t35 = −2.455, $p < 0.05$). When considering performance at the TOL test, no significant differences were found between ASD and TD children (ASD M = 63.53 vs. TD M = 65.5; t35 = −.219, $p > 0.05$). While both groups scored at the level expected for their age, ASD children showed lower receptive verbal abilities than TD children as measured by the PPVT-R (ASD M = 97.18 vs. TD M = 107.5; t35 = −2.421, $p < 0.05$) (see Table 2.3 in Appendix B for a detailed overview).

2.2.2 Stimuli and procedure

Figure 2.1 shows the experimental set up. The participant was asked to stand on a floor marking tape parallel to the lateral edge of a table (at about 22 cm from the table). At the start of each trial, a white plastic cylinder (height = 30 cm; diameter = 1.6 cm; weight = 135 g) with a thin plastic base (height = 0.5 cm; diameter = 10 cm) was placed on the table at a distance of 25 cm in front of the participant (*home position*). A wired grid stand with a grid shelf (15 x 30 cm) attached to it stood parallel to the short side of the table, to the left of the participant (see Figure 2.1). The grid shelf was designated as the *target position*.

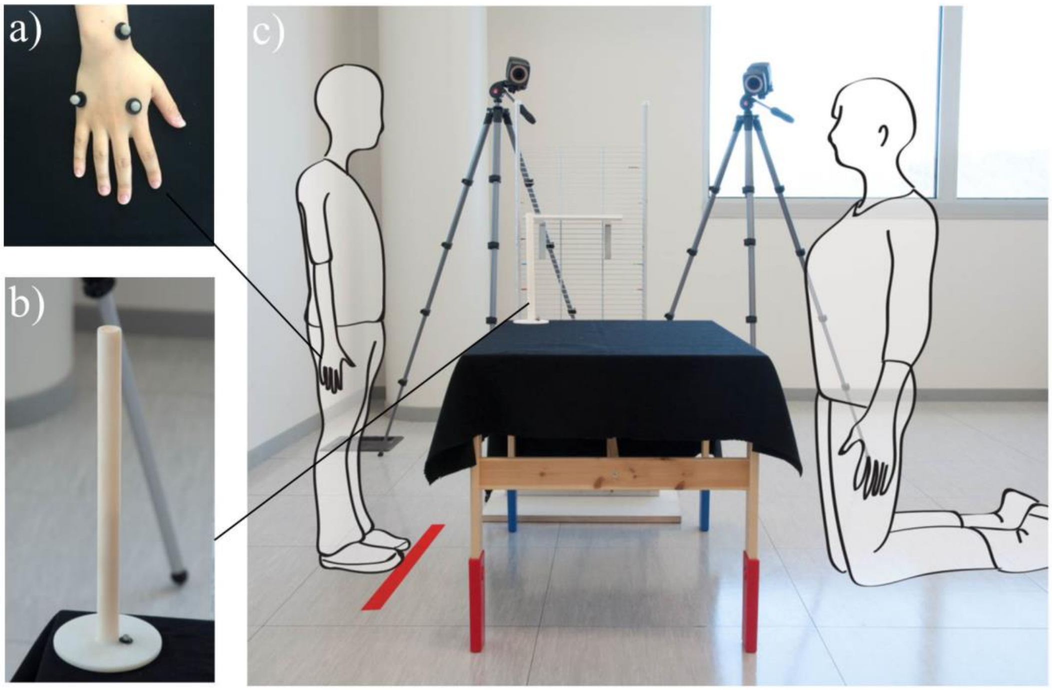

Figure 2.1. A schematic representation of materials and experimental set-up were used to test grasp-height effect. The markers' position on the participants' right hand (panel a) and the cylinder (panel b) were used to measure the grasp height effect during the unimanual, bimanual, and joint tasks (panel c).

Both the height of the home position and the height of the target position were adjusted to the participant's height. The initial height of the table was levelled with the elbow height of the participant when standing (please refer to Table 2.4 in Appendix B for details). The grid shelf (target position) could be positioned at one of three heights: at the same height of the home position (middle), 20 cm higher, (high) or 20 cm lower (low) than the home position. This allowed for comfortable initial and final postures (e.g., no need for bending or arm stretching).

Throughout all experimental sessions, the same female experimenter, kneeling at the opposite side of the table, interacted with the participants. The grasp height effect was tested in three tasks:

- Unimanual task: the participant reached towards, grasped the cylinder with the right hand and then moved it from the home position to the target position;
- Bimanual task: the participant grasped the cylinder with their right hand, passed it on to their left hand and then moved it to the target position;
- Joint task: the participant grasped the cylinder with their right hand, and then passed it on to the experimenter, who took hold of it with their right hand and moved it to the target position. The experimenter was at a distance of about 1 meter from the participant.

Participants performed a series of three consecutive movements for each of the three target position heights (low, middle, high) for each of the three tasks (unimanual, bimanual, joint), making a total of 27 movements. The order of tasks and target position heights were balanced across participants.

At the start of the first trial, the child was instructed to stand on the floor marking tape. Once the child stood on the mark, the experimenter positioned the grid shelf at one of the three heights (low, middle, or high) and instructed the child on how to perform. Participants were asked to keep their left hands by their sides at all times and to keep their right hands by their sides between trials. They were asked to take hold of the cylinder with their right hand and, after completion of the task, to return that hand to the side of their body (i.e., let it hang down). At the end of the trial, the experimenter returned the cylinder to the home position. This procedure was repeated three times. When three trials were completed, the experimenter removed the grid shelf and, consulting a previously prepared design sheet, positioned the shelf to another height, whereupon the sequence of the three movements was repeated.

Children were asked to perform in a relaxed manner, moving at a comfortable speed. Throughout the experiment, the experimenter carefully monitored the children's performance and reminded them of the instructions, if necessary. In order to become familiarized with the procedure, the children performed two practice trials before each experimental task. There was a short pause of approximately 20 seconds between each trial and a longer pause of about 2 minutes between tasks. The entire experiment lasted around 20 minutes.

2.2.3 Kinematics recording and data processing

To track and record the children's grasp height, we used a near-infrared camera motion capture system (frame rate = 100 Hz; Bonita Vicon Motion Systems Ltd, Oxford, UK). Six cameras were located in a semicircle at a distance of 1.5 – 2 m from the table on which the plastic cylinder was placed (see Figure 2.1). Each child was outfitted with three lightweight retro-reflective hemispheric markers (10 mm in diameter) placed on the metacarpal-phalangeal joint of the index and little fingers as well as on the radial aspect of the wrist of the right hand (see Figure 2.1). A retro-reflective hemispheric marker was also placed on the base of the cylinder (see Figure 2.1). After data collection, each trial was individually inspected for correct marker identification and then run through a low-pass Butterworth filter with a 6 Hz cut-off. For data processing and analyses, a custom software (Matlab; MathWorks, Natick, MA) was used to compute the *grasp height*, defined as the distance (mm) between the marker placed on the index metacarpal-phalangeal joint of the hand and the marker placed on the cylinder at lift onset (i.e., the first frame in which the vertical displacement of the marker on the cylinder exceeded 0.5 mm).

2.2.4 Data analyses

We performed two complementary analyses. In our first analysis, to compare grasp height across tasks and groups, we performed a mixed factorial Analysis of Covariance (ANCOVA) with task (unimanual, bimanual, joint) and target position height (low, middle, high) as within-subjects factors and group (ASD, TD) as between-subjects factors. Chronological age, stature, and FS IQ were closely matched for ASD and TD children (see 'Participants' section). Despite this careful matching, with nearly identical age, stature, and FS IQ averages between groups, there is always some remaining variation across participants in these measures. To control for this, we entered the children's age, stature, and FS IQ as covariates (for a description of a similar rationale, please refer to Pallett et al. 2014). Analysis of covariance allowed us to reduce within-group error variance while testing the between-group differences adjusted for the covariates (see Field 2013). We did not include MABC-2, TOL, and PPVT-R as covariates because these variables measure attributes that are intrinsic to the disorder and hence their inclusion would lead to erosion of the effect of group (Adams et al. 1985; Evans and Anastasio 1968; Lord 1967; Lord 1969; Miller and Chapman 2001; Tupper and Rosenblood 1984). Post-hoc tests (Bonferroni's correction; $p < 0.05$) were applied to explore significant effects and interactions.

In a second analysis, to capture the relationship between motor and cognitive functioning and prospective control, we correlated (by means of Pearson's correlation) the difference in grasp height with movement skills (as measured by MABC-2 total score), executive planning skills (as measured by the TOL), and receptive vocabulary (as measured by the PPVT-R). In the ASD group, the difference in grasp height was further correlated with the degree of autistic severity (as measured by ADOS-2 and ADI-R tests; for the ASD group only). The difference in grasp height was calculated by the difference between the average grasp height when placing the cylinder on the lower target position and the average grasp height when placing the cylinder on the higher target position. The calculation was made for each participant in the TD and ASD groups, and for the unimanual, bimanual, and joint tasks separately.

2.3 Results

Missing values accounted for < 1% of the data (3 over 459 trials in ASD group and 1 over 540 in the TD group). No values were removed as outliers (defined as grasp heights deviating 2.5 SD from their respective averages).

2.3.1 Distribution of grasp height as a function of the target position in TD and ASD individuals

The distribution of grasp height for each task in TD and ASD individuals is illustrated in Figure 2.2. To favour comparison, data for each TD and ASD participant are reported within the same graph. For the unimanual task (Figure 2.2a), the distribution of grasp heights tended to cluster as a function of the target position, with participants being more likely to grasp the cylinder lower when the target position was high (red dots) than when it was low (blue dots). This pattern was apparent in both TD and ASD children.

As illustrated in Figure 2.2b, in the bimanual task, in both groups, grasp heights for high and low target positions showed a larger degree of overlap, with just a few children grasping the cylinder higher when the target position was high and lower when it was low, as predicted by the grasp height effect for bimanual actions. Interestingly, a larger proportion of children in both groups grasped the object in the same way as in the unimanual task (i.e., lower when the target position was high, higher when target position was low), thus violating the grasp height effect.

As for the joint task, inspection of grasp heights in Figure 2.2c suggests that, aside from a small number of children in the TD group (i.e., five children who grasped the cylinder higher when the target position was high, lower when the target position was low), the majority of children in both groups did not show a clear grasp height modulation to the partner's end posture. Qualitatively, it thus appears that prospective sensorimotor control for joint actions was not yet fully developed in the tested age range.

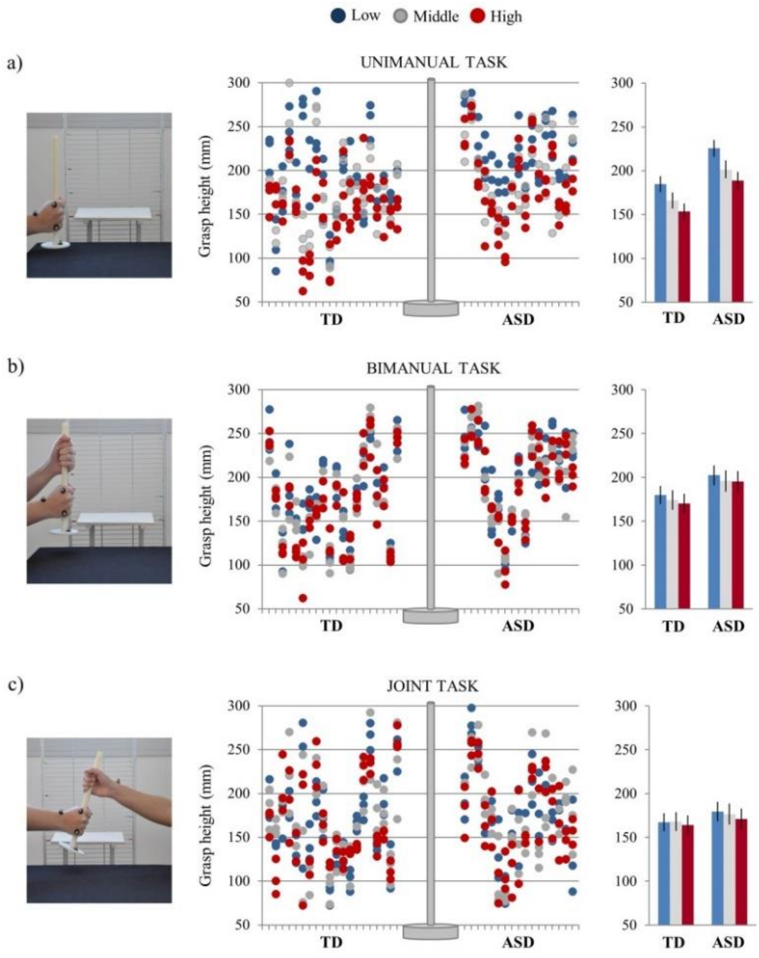

Figure 2.2. Grasp height as a function of the target position. Dot plots illustrating grasp height shown by individual participants (in the order in which they were recruited) in the unimanual (panel a), bimanual (panel b), and joint tasks (panel c). Each dot represents a trial and is colour-coded by target position. Bars on the right part of the figure represent grasp height (mm) in ASD and TD children as a function of different heights of the target platform. Error bars indicate standard error.

2.3.2 Grasp height across tasks in TD and ASD group

The ANCOVA with age, stature, and FS IQ as covariates revealed no main effect of *group* (F1, 32 = 3.012; $p = 0.092$; $\eta^2 = 0.086$), but it did show a significant *group* by *task* interaction (F1, 32 = 5.069; $p = 0.031$; $\eta^2 = 0.137$). Post-hoc contrasts indicated that children in the ASD group grasped the cylinder lower in the joint task than in the unimanual task ($p = 0.001$) and in the bimanual task ($p = 0.035$). No similar differences were found for the TD group ($p_s > 0.834$). The interaction *task* by *target position height* was also significant (F1, 32 = 8.828; $p = 0.006$; $\eta^2 = 0.216$), resulting from a significant grasp height effect in the unimanual task ($p_s < 0.005$) but not in the joint task ($p_s > 0.529$). As for the bimanual task, post-hoc contrast revealed that children grasped the object lower when the target position was high compared to low ($p = 0.016$). This pattern violates the grasp height effect, thus confirming the impression gleaned from Figure 2b. No other contrast was significant ($p_s > 0.148$).
The interaction *task* by *target position height* was further qualified by a three-way *task* by *target position height* by *FS IQ* interaction (F1, 32 = 4.877; $p = 0.034$; $\eta^2 = 0.132$), indicating that the children's IQ influenced the modulation of the effect of shelf height across tasks. To explore this effect, we examined the *task* by *target position height* interaction at different levels of FS IQ: lower IQ (FS IQ < 100; N = 17) and higher IQ (FS IQ ≥ 100; N = 20). In the unimanual task, children with a higher IQ adjusted their initial grasp height such that a comfortable end-state was achieved at all three target positions ($p_s < 0.039$; see Figure 2.3a). Children with a lower IQ, in contrast, only showed a significant modulation of grasp height for low compared to middle target positions ($p = 0.048$; see Figure 2.3b). In the bimanual task, whereas children with higher IQ showed no modulation of grasp height ($p_s > 0.448$), children with a lower IQ tended to grasp the cylinder higher when the target position was low than when it was high ($p = 0.028$), thus showing a pattern opposite to that predicted by the grasp height effect (Figure 2.3). No modulation of grasp height to target position was found for children with either a higher or lower IQ in the joint task (all $p_s > 0.198$).

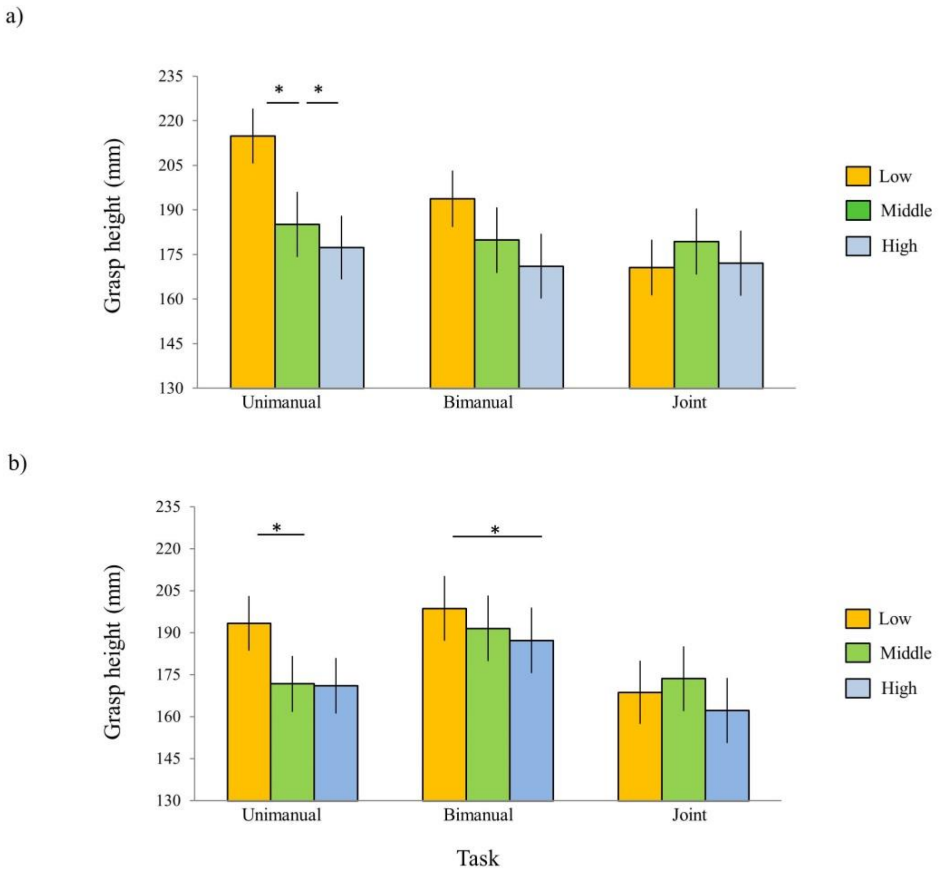

Figure 2.3. Graphical representation of the *task by target position* interaction at different levels of FS IQ. Grasp heights for low (light grey bars), middle (dark grey bars), and high (black bars) target positions in the unimanual, bimanual and joint tasks for higher IQ (panel a) and lower IQ children (panel b). Asterisks indicate significant differences ($p < 0.05$). Vertical lines represent standard errors.

Finally, the ANCOVA revealed a significant *task* by *stature* interaction (F1, 32 = 5.619; $p = 0.024$; $\eta^2 = 0.149$), resulting from children with lower stature (< 139 cm; N = 18) grasping the cylinder lower in the joint task than in the unimanual task ($p = 0.002$). Children with a higher stature (≥ 139 cm; N = 19), in contrast, did not show differences in grasp height as a function of task ($p = 1$). In the joint task, children were requested to grasp the target object and hand it to experimenter, the distance between the child and the experimenter being of about 1 meter. One possible explanation is thus that children with lower stature (and possibly shorter arms) adopted a lower grasp so to minimize the awkwardness of the hand posture when handing the object over to the partner.

2.3.3 Relationship between motor and cognitive functioning and prospective control

The correlation analysis revealed no significant association between motor, linguistic, and executive functions (as measured by MABC-2, PPVT-R, and TOL) nor differences in grasp height in either the TD group ($p_s > 0.199$) or the ASD group ($p_s > 0.53$). The association between the degree of autistic severity and differences in grasp height in ASD children was also not significant (ADOS-2 Total Score: $p_s > 0.209$; ADOS-2 Social Affect: $p_s > 0.300$; ADOS-2 Restricted and Repetitive Behaviors: $p_s > 0.383$; ADI-R: $p_s > 0.083$).

2.4 Discussion

We tested 17 children with an independent clinical diagnosis of ASD on a variety of object manipulation tasks designed to investigate the grasp height effect in individual and social contexts and compared their performance to that of 20 TD children matched for age, stature, handedness, and FS IQ. ASD children were significantly impaired in motor skills, as evaluated by MABC-2. Nevertheless, in the three object manipulation tasks, which assessed unimanual, bimanual, and joint prospective control, they performed as well as TD children. In both groups, we found a significant grasp height effect in the unimanual task, but not in the bimanual and joint tasks. These findings challenge the hypothesis of a general prospective sensorimotor planning deficit in autism and suggest that not all motor processes are impaired in individuals with autism spectrum disorder. In what follows, we first consider the relationship between our results and other studies examining prospective control in autism. Next, we discuss some of the factors that may account for modulation of grasp height across the three tasks.

2.4.1 Do children plan ahead? TD versus ASD children

Previous studies that have sought to examine prospective sensorimotor planning in children with ASD have yielded conflicting results. Some studies indicate that prospective control is impaired in children with ASD (Hughes 1996; Scharoun and Bryden 2016). For example, Hughes (1996) found that 12- and 13-year-old children transported a dowel using an underhand grip as opposed to the overhand grip used by younger (4-year-old), typically developing children. The underhand grip resulted in an uncomfortable end-state posture, indicating a lack of prospective planning. Other studies, however, revealed no significant group differences (Gonzalez et al. 2011; Hamilton et al. 2007; van Swieten et al. 2010). Using an orientation matching task, van Swieten et al. (2010), for example, report that 9- to 14-year-old children with ASD chose postures that led to end-state comfort about 50% of the time, which was similar to the age-matched controls. Hamilton et al. (2007) also tested a group of twenty-five autistic children on the grip selection task and found no group differences.

There are several possible causes for these inconsistencies, including differences between the task and procedures, the sample size and age of participants, as well as their cognitive and motor development. Our study rectifies these limitations in three ways. Firstly, we performed a comprehensive set of measurements spanning higher order planning for both individual and joint object manipulations. Secondly, unlike in other studies, participants were matched for age, gender, stature, handedness, and FS IQ. Finally, whereas all previous studies employed video-analysis of dichotomous outcome measures (i.e., grip selection), we used kinematic recordings of a more sensitive continuous measure, namely the height at which the object was initially grasped to later be moved to the target position. This is important as dichotomous measures may potentially cloud differences in motor patterning (Janssen and Steenbergen 2011).

Kinematic analysis revealed a significant grasp height effect in the unimanual task, yet the measured effect was similar in the TD and ASD groups. Similarly, we found no differences in grasp height between groups in the bimanual and joint tasks. We emphasize that it is not that we failed to measure any effect in either the TD or ASD group; to the contrary, we reliably measured a grasp height effect in the unimanual task and a significant inversion of this effect in the bimanual task. This provides strong evidence that the lack of measurable differences between the TD and the ASD populations is not a consequence of poor resolving power associated with our paradigm.

Finally, it can be observed that ASD group exhibited a similar ability as TD group in terms of prospective control but, when tested at the MABC-2, their performance was lower. While on the surface this result may sound puzzling, it should be observed that MABC-2 battery spans from “fine” (e.g., manual dexterity) to “gross” motor skills (e.g., walking, balance, and so on), encompassing a number of different processes relating to sensory, planning and execution aspects of motor control. This opens to at least two considerations. First, as also noted by Gowen and Hamilton (2013), motor battery as MABC-2 makes hard to know which specific motor processes are abnormal in autism. Second, it might well be that MABC-2 and our task picture different motor aspects. For instance, activities as threading beads or drawing trail might be seen as relying more onto online control and multi-sensory signals integration than actually it is for performing tasks similar to those used here.

2.4.2 Orders of planning and planning span

Children in both groups showed the grasp height effect in the unimanual task but not in the bimanual and joint task. What factors may account for these task modulations?

One factor that could account for the observed modulations is related to the orders of planning, i.e., what needs to be done one (second-order), two (third-order), or several actions later. The unimanual task looked for second-order effects, reflecting the influence of what the subject intends to do next with the object (i.e., move the object to the target position). The bimanual and the joint tasks looked for third-order effects, reflecting the influence of what is to be done after that (i.e., pass the object to the other hand or to the co-actor to move it to the target position; see Rosenbaum et al. 2013). It is thus possible that the task-dependent modulations reflect differences in the planning span (Rosenbaum et al. 2013), with third-order planning exceeding the action planning capabilities of 7- to 11-year-old TD and ASD children. Contrary to this, however, recent work has shown that 7-year-old children, but not 3- and 5-year old children, demonstrate evidence for third-order joint action planning (Paulus 2016). Moreover, an explanation in terms of planning span cannot account for differences in the bimanual and joint task. While the number of action steps may contribute to the observed patterns, it seems thus unlikely that the planning span is the only critical factor.

Although results did not reveal a significant grasp height effect in the bimanual task, it would be incorrect to say that children totally failed to consider the more distal action goal in this task. Both qualitative as well as quantitative evidence indicate that in the bimanual task a good proportion of participants regularly grasped the cylinder higher (with their right hand) when the target position was low compared to when it was high. This shows that children did not ignore the height of the target position; the error rather points to a specific problem in planning the appropriate sequence of moves. At first glance, this might appear as an executive planning deficit, reflecting the inability to represent the sequence of intermediate choices or moves that must be arranged in order to achieve a desired end-state. However, if this were the case, we would expect an association with executive function performance. Correlation analysis showed that this was not case (van Swieten et al. 2010; Wunsch and Weigelt 2016).

What the grasping patterning in the bimanual task suggests is rather that children engaged in action planning, but they did so in a ‘unimanual’ way. In other words, they grasped the object with their right hand at the height that would have been appropriate as if they intended to move it with their right hand to the target position. This behavior may reflect the potential conflict between unimanual and bimanual planning constraints. Conflict between grasping strategies has been shown to increase the overall cognitive demands of a task and interfere with the ability to integrate proximal and distal action segments into a single action plans (Stöckel and Hughes 2015). As a result, children who do not possess the cognitive resources to resolve the conflict may be biased to select a non-compliant grasp posture (Paulus 2016; Stöckel et al. 2012). However, to date, previous studies which investigated anticipatory effect through bimanual tasks required participants to use both hands to grasp two bars simultaneously (see e.g., Janssen and Steenbergen, 2011). The presented study describes a novel bimanual task in which the position of the first hand on the object reflects whether children considered not only what they had to do next (i.e., pass the object to the other hand), but also further step (i.e., place the object to the target platform). Therefore, differences in task and procedure may hinder comparison between previous studies. Indeed, in our study, grasping the object with one’s right hand in the bimanual task may have triggered the planning that would have been appropriate to complete the task with one hand. This interpretation is further strengthened by the fact that this ‘unimanual bias’ was most pronounced in children with lower FS IQ, i.e., children who arguably did not possess the cognitive resources to deal with the conflict.

All of these considerations raise questions about the grasping pattern displayed by higher FS IQ participants. Could this apparently random pattern reflect the not yet fully developed ability to select an appropriate grasp when unimanual and bimanual action planning are in conflict? Would removing the conflict facilitate compliance with the bimanual grasp height effect? This could be tested by manipulating task constraints (e.g., by asking participants to initially grasp with their left hand in the bimanual task so to avoid conflict with the unimanual strategy; see Stöckel and Hughes 2015, for a similar approach). If removing conflict decreases cognitive costs, we should see an improvement in grasp height performance.

2.4.3 Effect of social context

Finally, it is also worth considering the differences between third-order bimanual and joint action planning. Bimanual and joint object manipulation differ in a trivial sense because, in a joint task, each actor is responsible for only half of the task, i.e., for one hand, so to say. However, accumulating evidence indicates that when two adult co-actors perform a task together, each actor integrates the co-actor's action in his or her action planning (Sebanz et al. 2006). Some studies indicated that co-representation effects of this sort have also been reported in children aged 5 years and up (Milward et al. 2014; see also Meyer et al. 2016). Indeed, Meyer and colleagues (2016) found that by 5-years-old children clearly reflected that they flexibly accommodated to their action partner. These results contrast with findings of those studies reporting the prospective planning in childhood suggesting a further development in motor planning abilities with increasing age (Van Swieten et al., 2010). However, it remains unknown whether and to what extent young children spontaneously represent the co-actor's end-state in a joint task. Some evidence speaks in favour of an even more protracted development, with even 9- to 14-year- old children lagging significantly behind adults in their performance (van Swieten et al., 2010). Moreover, Thibaut and Toussaint found that initial grasps were modulated to afford final thumb-up postures in 42% of the 4- year olds, in 66% of the 6-year olds, in 49% of the 8-year olds, and in 81% of the 10-year olds. Why there was a drop in the percentage of children who showed the effect in the 8- year-old range was unclear. Authors speculated that some form of motor reorganization may take place at around this age. This pattern of results highlighted a developmental trend, although it also suggested incomplete acquisition of prospective planning in the 9–14 years-age range (Thibaut et al.

2010). Moreover, it is also around the same age that children show increasingly more cognitive flexibility and inhibitory control (Carlson 2005), both crucial prerequisites for inhibiting dominant responses and adjusting their own plans to another person. Paulus (2016), for example, found that 7-year-old children, but not 3- and 5-year-old children, adjusted their own motor planning to accommodate the end-state of another person. In the study by Paulus (2016), however, children received some critical feedback when not performing adequately – the partner frowned, uttered a sceptical “mhmm” and waited for 3 s, demonstrating their difficulty in dealing with the problem.

In the present study, in contrast, children received no feedback whatsoever. Moreover, because of the nature of the task, it is implausible that they perceived the partner’s discomfort when not performing adequately. It is thus possible that they did not represent the partner’s end-state. Again, however, it would be incorrect to say that children totally failed to consider joint task constraints. In the joint task, we found no evidence of unimanual bias. This is at odds with the bimanual task in which a good proportion of children grasped the object in a ‘unimanual way’. Why might this be? While the task design does not allow us to draw conclusions regarding the underlying computational mechanisms, it suggests that grasp performance was influenced by the social context of the task, i.e., the presence of someone else in the action scene. This is further supported by the finding that, regardless of the height of the target position, ASD children grasped the object lower in the joint task. Although this effect does not reflect co-representation of the partner’s end state, it suggests that ASD children adjusted their behavior to accommodate the other’s action. Future studies will be necessary to understand the exact computational characteristics of this phenomenon. A speculative possibility is that having difficulties in anticipating the partner’s movements, children in the ASD group used a lower grasp to allow more space for the partner’s hand.

Chapter 3

Self and Other-action Kinematic Modulation in Autism [2]

3.1 Introduction

The simple act of picking up a water glass is the product of multilayered cognitive plans and sophisticated neural computations (Flanagan et al. 2006; Rosenbaum et al. 2012). At the heart of these computations is prediction: motor performance anticipates futures states. This goes beyond anticipating the properties of the object being reached for (Ansuini et al. 2015; Podda et al. 2017). People alter their manipulative behavior in anticipation of what they plan to do next with the object, e.g. if they plan to drink from the glass or pass the glass to another person (Cavallo et al. 2016). Moreover, during joint actions, they may alter their initial grasp to accommodate the onward actions of others. That is, they alter their grasp based on what they expect their partner will do next with the object (Ray and Welsh 2011). Failure to develop this primary form of prospective motor control has been proposed to contribute to faults in higher mind functions of individuals with autism spectrum disorders (ASD) (Trevarthen and Delafield-Butt 2013; Trevarthen, 2016). Yet, the very notion of abnormalities in the prospective motor control in autism remains controversial. Empirical supports are mixed and interpretations are varied, potentially because no common pattern characterizes ASD individuals homogeneously. Heterogeneity in individual responses is a consistent finding in autism research (Byrge et al. 2015; Humphreys et al. 2008; Müller et al. 2002; Towgood et al. 2009) and has been proposed to

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[2] The study presented here is part of the paper published as: Cavallo, A., Romeo, L., Ansuini, C., Podda, J., Battaglia, F. M., Veneselli, E., Pontil, M., & Becchio, C. (2018). Prospective motor control obeys to idiosyncratic strategies in autism. *Scientific Report*, 8. doi: 10.1038/s41598-018-31479-2.

reflect a distinctive characteristic of neural activity in ASD (Hahamy et al. 2015). However, to date, no study has assessed its impact on prospective motor control. In the current study, we introduce a novel approach for parsing this heterogeneity through machine learning modeling of the kinematics of children with ASD and typically developing (TD) children performing a sequential object manipulation task. Computationally, the task of uncovering prospective control strategies governing manipulative behavior can be framed as a pattern-classification problem. Specifically, can the way in which an object is grasped reveal the action to be performed next? Our approach draws on ideas from pattern-classification for analyzing subtle changes in kinematics as spatiotemporal patterns and linking them to the forthcoming action, be it self- or other-performed. By applying machine learning methods to movement features, we first assessed the extent to which children in the ASD group prospectively altered their manipulative behavior in comparison to children in the group. Using multivariate cross-classification (Cichy and Teng 2017; Kaplan et al. 2015), we next investigated the correspondence between prospective control strategies across ASD and TD groups. Finally, we quantified individual pattern distortions within each group and correlation with ASD symptoms. This multilevel pattern-classification approach was applied to test prospective control to accommodate both one's own and another person's action plans. Observations of grasping suggest that while 3-years-old TD children are already able to plan self-actions in advance, development of prospective of other-actions is protracted during middle childhood, starting to emerge around 7 years of age (Paulus 2016). Evidence of similar developmental timeline in ASD to date has been sparse and inconsistent (Ansuini et al. 2018; Scharoun and Bryden 2016), which again may be a consequence of variability among individuals with autism. Consistent with this notion, our results reveal a marked heterogeneity within the ASD prospective control strategies, suggesting that ASD children vary idiosyncratically in the ways they alter their grasp to accommodate self- and other-actions.

3.2 Materials and methods

3.2.1 Participants

Twenty children with Autism Spectrum Disorder (ASD) without accompanying intellectual impairment (ASD group: 18 males) and 20 age-matched typically developing children (TD group: 16 males) were recruited from the Child Neuropsychiatry Unit of the ‘Giannina Gaslini’ Hospital and schools in Genova. Groups were matched for age (TD M ± SD = 9.5 ± 1.5 years.months; ASD = 9.8 ± 1.5 years.months; t38 = - .665, *p* = 0.510), stature (TD M ± SD = 137.7 ± 9.1 cm; ASD = 140.5 ± 8.3 cm; t38 = 1.031, *p* = 0.510) and Full Scale IQ as measured by the Wechsler Scale of Intelligence (WISC IV; Wechsler 2003) (TD M ± SD = 102.8 ± 9.4; ASD = 98.5 ± 11.1; t38 = 1.325, *p* = 0.309) and WISC IV subscales (verbal comprehension, perceptual reasoning, working memory and processing speed; Holm-Bonferroni corrected p_s ranging from 0.104 to 0.771; see Table 3.1 in Appendix B for details). Children with ASD were diagnosed according to DSM-5 (American Psychiatric Association 2013) criteria. The Autism Diagnostic Observation Scale (ADOS-2; Lord et al. 2012) and Autism Diagnostic Interview-Revised (ADI-R; Rutter et al. 2003) were administered by two experienced professionals. ASD children met the cut-off on total ADOS-2 score (>=7) and on at least three out of four subscales of the ADI-R (see Table 3.2 in Appendix B). All ASD and TD children had normal or corrected-to-normal vision and were screened for exclusion criteria (pharmacological treatment, dyslexia, epilepsy, and any other neurological and psychiatric conditions). Both ASD and TD group were assessed for executive functions abilities by means of the Tower of London (TOL; Anderson et al. 1996) test. This test revealed no significant differences between TD and ASD children (TD M ± SD = 29.35 ± 3.54; ASD = 29.35 ± 2.80; t38 = 0, *p* = 0.999). All but two of the children (one in the ASD group and one in the TD group) were right-handed according to the Edinburgh Handedness Inventory (Oldfield 1971).

3.2.2 Stimuli and procedure

Figure 3.1 shows the experimental set up. Children were tested individually in a quiet room. They were seated on a height-adjustable chair with their right elbow and wrist resting on a table (height = 64 cm; length = 100 cm; width = 60 cm). In order to guarantee a repeatable start position, they were asked to maintain their forearm in a pronated position with their right arm oriented in the parasagittal plane passing through the shoulder and their right hand in a semi-pronated position. They were asked to keep their thumb and index fingers closed in a pincer grip on a tape-marked point (at about 7 cm from table edge) on the working table. An open plastic bottle filled with water (base diameter = 5 cm; height = 18 cm; weight = 225 g) was positioned on the table at a distance of 44 cm from children's midline. Throughout the entire experimental session, the same female experimenter (co-actor), sitting at the opposite side of the table, interacted with the children. Depending on conditions, one of two target objects was placed on the table: a box (height = 6 cm; diameter = 10 cm) or a glass (height = 10 cm; diameter = 6.5 cm). For grasp-to-place and grasp-to-pour trials, the target object was located 19 cm away from the bottle. For grasp-to-pass trials, the target object was located closer to the co-actor's right hand, 43.5 cm away from the bottle.

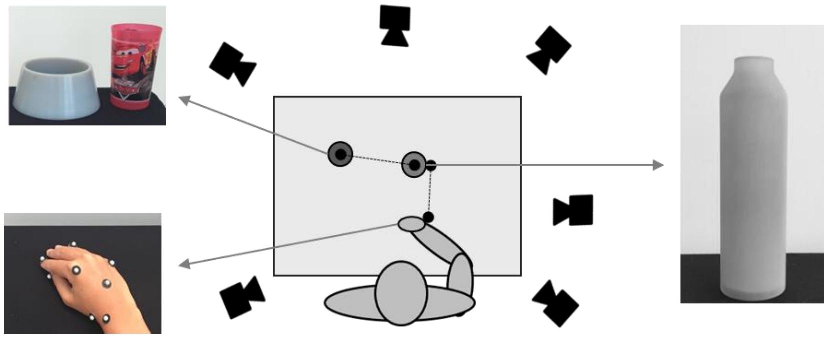


Figure 3.1. A schematic representation of the experimental set-up used to assess whether children from both TD and ASD group prospectively alter their manipulative behavior depending on different self or other's action plans.

Children performed a series of 12 consecutive grasps for each condition; they made a total of 48 movements. In each trial, children were asked to perform at a natural speed after an auditory tone. During grasp-to-place and grasp-to-pour trials, the experimenter was asked to look down at the table, with her arms along the body. During grasp-to-pass trials, she was asked to look at the object, resting her right wrist on the table, with her thumb and index fingers closed in a pincer grip on a tape-marked point on the working table. To avoid online influences of action perception on action production, the experimenter was instructed to start the movement only after the child had grasped the object. The order of block presentation was pseudo-randomized across participants. Before each block, there were two practice trials to familiarize children with tasks. To avoid fatigue and lack of attention, children were given a two-minute pause at the end of each block. Testing required a single session of approximately 30 min per participant.

3.2.3 Kinematics recording and data processing

A near-infrared camera motion capture system (frame rate = 100 Hz; Bonita Vicon Motion Systems Ltd, Oxford, UK) was used to track and record the reach-to-grasp kinematics. Six cameras were placed at a distance of 1.5 – 2 m from the working table. The child's right hand was outfitted with 8 retro-reflective hemispheric markers (6.5 mm in diameter) placed on the metacarpal joint and the tip of the index and the little finger, the trapezium bone of the thumb, the radial aspect of the wrist and the center of the hand dorsum. After the data collection, each trial was individually inspected for correct marker identification and then run through a 6 Hz low-pass Butterworth filter. For data processing, a custom software (Matlab; MathWorks, Natick, MA) was used to compute two sets of kinematic variables. The first set of variables, expressed with respect to the original frame of reference (i.e., the frame of reference of the motion capture system, termed as the global frame of reference), included:

- wrist velocity, defined as the module of the velocity of the wrist marker (mm/sec);
- wrist height, defined as the z-component of the wrist marker (mm);
- grip aperture, defined as the distance between the marker that was placed on the tip of the thumb and the marker placed on the tip of the index finger (mm).

To better characterize hand movements at the joint level, the second set of features was expressed with respect to a local frame of reference centered on the hand (i.e., F_{local}; see Ansuini et al. 2015 for a detailed description of this frame of reference). This set of features included:

- x-, y-, and z-thumb, defined as x-, y- and z-coordinates for the thumb (mm);
- x-, y-, and z-index, defined as x-, y- and z-coordinates for the index finger (mm);
- x-, y-, and z-finger plane, defined as x-, y- and z-components of the thumb-index plane, i.e., the three-dimensional components of the vector that is orthogonal to the plane. This feature provides information about the abduction/adduction movement of the thumb and index finger, irrespective of the effects of wrist rotation and of finger flexion/extension;
- x-, y-, and z-dorsum plane, defined as x-, y- and z-components of the radius-phalanx plane. This feature provides information about the abduction, adduction, and rotation of the hand dorsum, irrespective of the rotation of the wrist.

All features were computed only considering the reach-to-grasp phase of the movement, i.e., from ‘reach onset’ (i.e., the first time point at which the wrist velocity crossed a 20 mm/s threshold and remained above it for longer than 100 ms) to ‘grasp offset’ (i.e., the time at which the wrist velocity dropped below a 20 mm/s threshold), at intervals of 1% of the normalized movement time.

3.2.4 Data analyses

For each group of participants, SVMs with Gaussian Kernel were used to solve two machine learning tasks: i) classification of grasping movements followed by one of three onward self-actions (i.e. *place, pour*, and *pass*); ii) classification of grasping movements followed by one of two onward other-actions (i.e. *pass-to-place* and *pass-to-pour*). For both tasks, the *macro-F_1 score* was used as a measure of SVM classification performance. *Macro-F_1 score* can range between 0 and 1 and reflects the weighted average of the precision and recall of the model.

$$Macro - F_1\ score = 2 * \sum_{j=1}^{c} \frac{Precision(j) * Recall(j)}{Precision(j) + Recall(j)}$$

Where *j* represents the class (e.g. *grasp-to-pour*), precision is the result of the following:

$$Precision = \frac{True\ Positives}{True\ positives + False\ Positives}$$

And recall is the result of the following:

$$Recall = \frac{True\ Positives}{True\ positives + False\ Negatives}$$

Differently, from the standard *F_1 score*, the *macro-F_1 score* calculates metrics for each class and finds their unweighted mean, without taking class imbalances into account. For group-level analyses, *macro-F_1 scores* were computed from a stratified k-fold cross-validation scheme in which values were averaged. Stratification allows to obtain consistent results, both in terms of bias and variance, when compared to regular cross-validation (Long et al. 2010).

To evaluate the discriminative power of each kinematic feature in the planning of both self- and other-actions, we calculated for each participant and each kinematic feature the Fisher score. Given a dataset $\{(x_i, y_i)\}\,{}_{i=1}^{n}$ where $x_i \in \mathbb{R}^d$ and $y_i \in \{1, 2, \ldots, \mathrm{c}\}$ the Fisher score for the k-th feature is defined as:

$$Fisher\ score\ (x^k) = \frac{\sum_{j=1}^{c} p_j(\mu_j^k - \mu^k)}{\sum_{j=1}^{c} p_j\ (\sigma_j^k)^2}$$

Where and are the mean and the standard deviation of the *j*-th feature, while and denote the mean of the whole dataset corresponding to the *k*-th feature and the class prior probability, respectively.

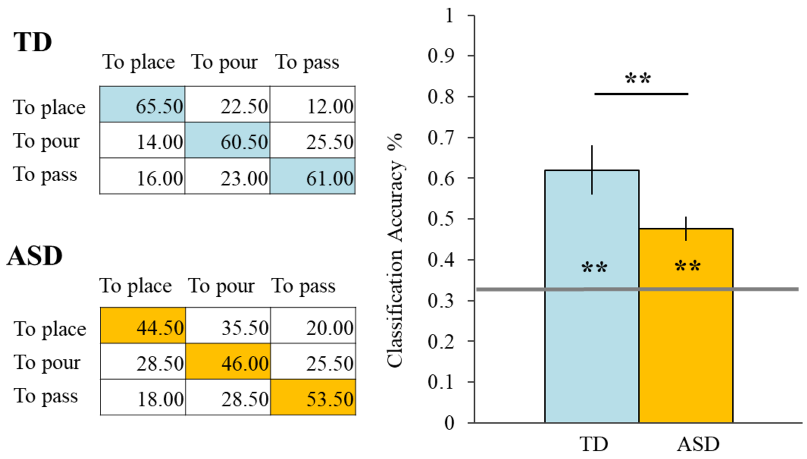
In order to allow comparisons between TD and ASD children, Fisher scores of each feature were then normalized by dividing each score by the sum of all scores obtained in both groups. The sum of raw Fisher scores of each kinematic feature within each participant provided an individual Fisher score to be correlated with other tests.

3.3 Results

We used a sequential object manipulation task to test prospective motor control in children with ASD (N = 20) and FS IQ-matched typically developing (TD) children (N = 20). Children were instructed to reach towards and grasp an object (a bottle), to place it into a box (grasp-to-place), to pour some water into a glass (grasp-to-pour), or to pass the bottle to a co-actor (grasp-to-pass), who would then either place the bottle into the box (pass-to-place) or pour some water (pass-to-pour). A near-infrared camera motion capture system was used to record movement kinematics. Kinematic parameters of interest (N = 15, see ‘Kinematics recording and data processing’ section) were computed throughout the reach-to-grasp phase of the movement (from reach onset to the moment of contact between the fingers and the bottle, i.e., grasp offset) at intervals of 1% of the normalized movement time. The 1500 resulting features were used as predictors for all the classification analyses.

3.3.1 Prospective control of self-actions

To quantify changes in behavior as a function of self-action plans, we first trained a Gaussian Kernel support vector machine (SVM) to distinguish, separately for the ASD and the TD group, grasping movements followed by one of three onward self-actions: place, pour, and pass. Classification performance was computed as the resulting average of a leave-one-subject-out cross-validation procedure. The classification accuracy was used as a measure of classifier performance. To test whether classification accuracy significantly exceeded chance level, we randomly permuted the class labels ‘place’, ‘pour’, and ‘pass’ (500 permutations) and recomputed SVMs classification accuracy after each permutation. Classifier performance exceeded chance level (0.33) in both the TD group (M = .623, 95% CI= [.559, .687], empirical p after 500 permutations = 0.002) and the ASD group (M = .480, 95% CI = [.415, .545], empirical $p = 0.002$). This demonstrates that, in both groups, forthcoming self-demands resulted in anticipatory modifications of the initial grasping. Tailoring to the onward self-action was less pronounced in the ASD group than in the TD group as indicated by a lower classification accuracy (independent samples t-test, t38 = -3.285, $p < 0.01$). Figure 3.2 shows confusion matrices and classification accuracies for each of the two groups.



TD

	To place	To pour	To pass
To place	65.50	22.50	12.00
To pour	14.00	60.50	25.50
To pass	16.00	23.00	61.00

ASD

	To place	To pour	To pass
To place	44.50	35.50	20.00
To pour	28.50	46.00	25.50
To pass	18.00	28.50	53.50

Figure 3.2. Prospective control of self-actions. Confusion matrices and classification accuracies for TD and ASD group. The classification accuracy exceeded chance level (0.33; grey horizontal line) in both groups (empirical p_s after 500 permutations = 0.002) but was significantly lower in ASD compared to TD group ($p < 0.01$). Asterisks inside bars indicate significant differences from chance level classification. Asterisk outside bars indicates significant differences between groups (** = $p < 0.01$). Error bars indicate standard error.

To identify which kinematic features drove the classifier and evaluate the discriminative power of each kinematic feature over time, we next computed Fisher scores (see ‘Data analyses’ section). Fisher scores provide a measure of distance between data points in different classes of action. The higher the Fisher score, the greater the ability of a kinematic feature to discriminate between forthcoming actions. Figure 3.3 provide an overall view of the discriminative power of kinematic features in TD and ASD groups respectively. Visual inspection of the matrix revealed similar patterns of modulation in ASD and TD children. Specifically, in both groups, the specification of wrist height, index, and thumb height evolved gradually as the movement unfolded.

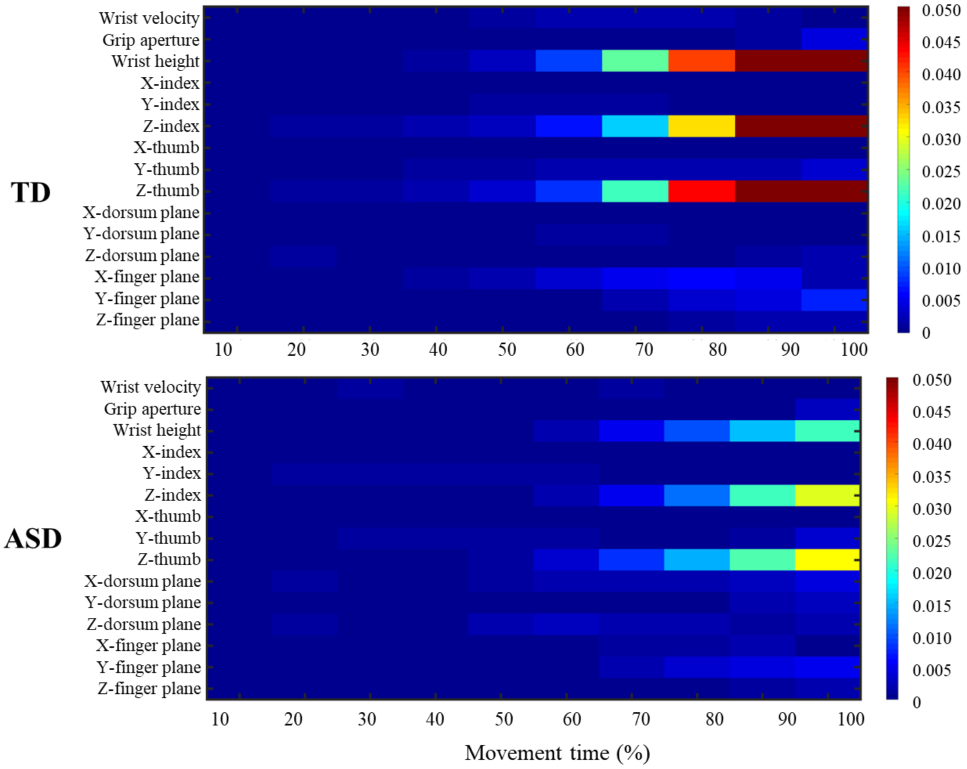
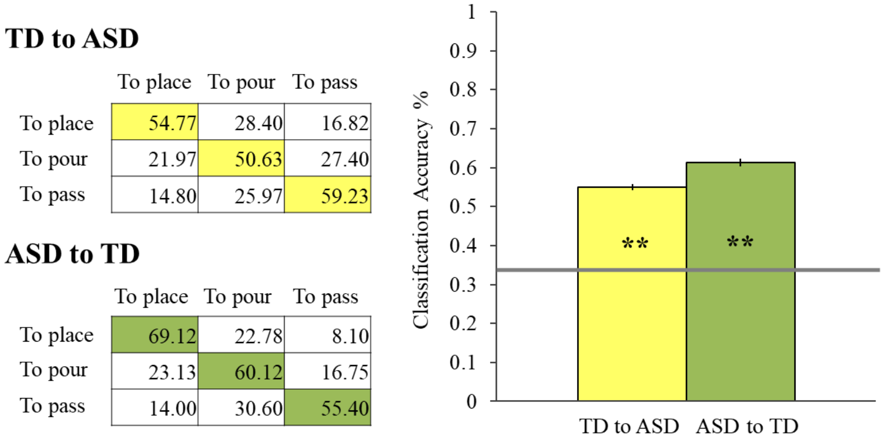


Figure 3.3. Discriminative power of kinematic features in TD and ASD group in prospective control of self-actions. The heatmaps show a graphical representation of Fisher scores of kinematic features over time. The higher the Fisher score, the greater the ability of a kinematic feature to discriminate between self-action plans. To allow comparison between groups, Fisher scores were normalized by dividing each score by the sum of all scores obtained in both groups.

To evaluate this impression and obtain quantitative evidence for similarity, in a subsequent analysis, we exploited an extension of the classification approach known as multivariate cross-classification (Cichy and Teng 2017; Kaplan et al. 2015). Cross-classification requires that a classifier is trained on data from one group (or condition) and tested on data of another. The cross-classification approach provides a direct measure of the similarity between the patterns underlying the two groups (or conditions). Following this logic, we trained the SVM classifier on one group (e.g., TD) and then tested it on its ability to classify the other group (e.g., ASD). Classifier performance was well above chance level (TD to ASD: M accuracy = .549, 95% CI = [.539, .558], empirical $p = 0.002$; ASD to TD: M accuracy = .616, 95% CI = [.605, .629], empirical $p = 0.002$) (Figure 3.4). This result corroborates the idea that ASD and TD children used similar prospective control strategies to accommodate subsequent self-actions.



TD to ASD

	To place	To pour	To pass
To place	54.77	28.40	16.82
To pour	21.97	50.63	27.40
To pass	14.80	25.97	59.23

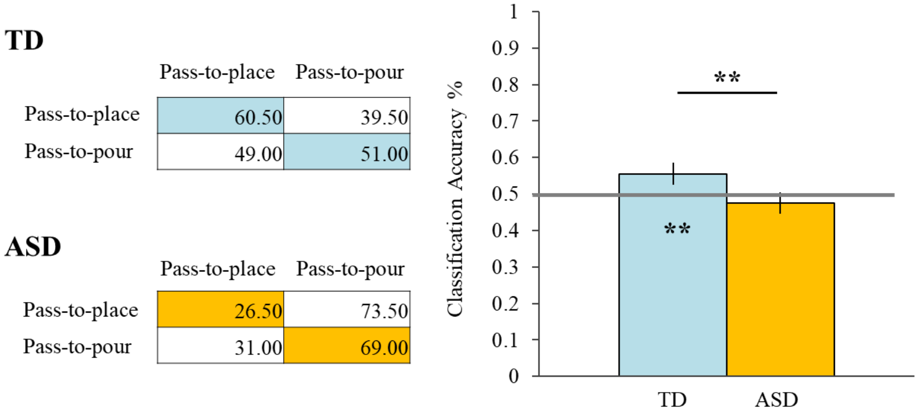
ASD to TD

	To place	To pour	To pass
To place	69.12	22.78	8.10
To pour	23.13	60.12	16.75
To pass	14.00	30.60	55.40

Figure 3.4. Cross-classification results for prospective control of self-actions. Confusion matrices and classification accuracies for a SVM classifier trained on TD and tested on ASD group (TD to ASD) and for a SVM classifier trained on ASD and tested on TD group (ASD to TD). The classification accuracy exceeded chance level (0.33; grey horizontal line) in both TD to ASD and ASD to TD cross-classifications (empirical p_s after 500 permutations = 0.002). Asterisks inside bars indicate significant differences from chance level classification (** = $p < 0.01$). Error bars indicate standard error.

3.3.2 Prospective control of other-actions

To verify whether ASD and TD children altered their initial grasp in anticipation of the co-actor's forthcoming action, we trained a SVM classifier to distinguish between pass-to-place and pass-to-pour actions. As for self-actions, for each group, classification performance was computed as the resulting average of a leave-one-subject-out cross-validation procedure. To test whether classification accuracy significantly exceeded chance level, we randomly permuted the class labels 'pass-to-place' and 'pass-to-place' (500 permutations) and recomputed the SVMs classification accuracy after each permutation. The classifier performed above chance (0.50) in the TD group (M = .558, 95% CI= [.508, .607], empirical $p = 0.01$), but not in the ASD group (M =.478, 95% CI = [.444, .510], t19 = 3.439, $p = 0.510$). The classification accuracy for the ASD group was also significantly lower compared to the TD group (t38 = -2.807, $p < 0.01$). Figure 3.5 shows confusion matrices and classification accuracies for the two groups.



TD

	Pass-to-place	Pass-to-pour
Pass-to-place	60.50	39.50
Pass-to-pour	49.00	51.00

ASD

	Pass-to-place	Pass-to-pour
Pass-to-place	26.50	73.50
Pass-to-pour	31.00	69.00

Figure 3.5. Prospective control of other-actions. Confusion matrices and classification accuracies for TD and ASD group. The classification accuracy exceeded chance level (0.50; grey horizontal line) only in TD group (empirical *p* after 500 permutations = 0.01) and was significantly lower in ASD compared to TD group ($p < 0.01$). Asterisks inside bars indicate significant differences from chance level classification. Asterisks outside bars indicate significant differences between groups (** = $p < 0.01$). Error bars indicate standard error.

We next computed Fisher scores to evaluate the discriminative power of each kinematic feature over time. In the TD group, as one would expect, the specification of different parameters of movement increased as the hand approached the object. In the ASD group, the specification of diverse aspects of movements appeared markedly attenuated, with only a few movement features showing an early, but not late, specification (Figure 3.6).

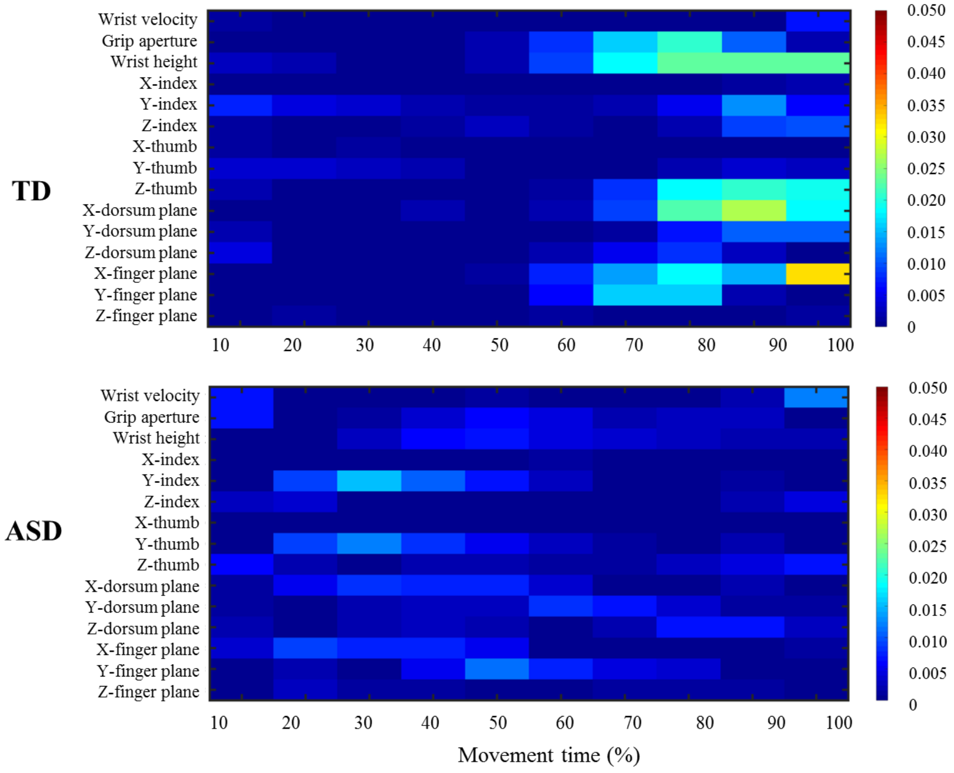
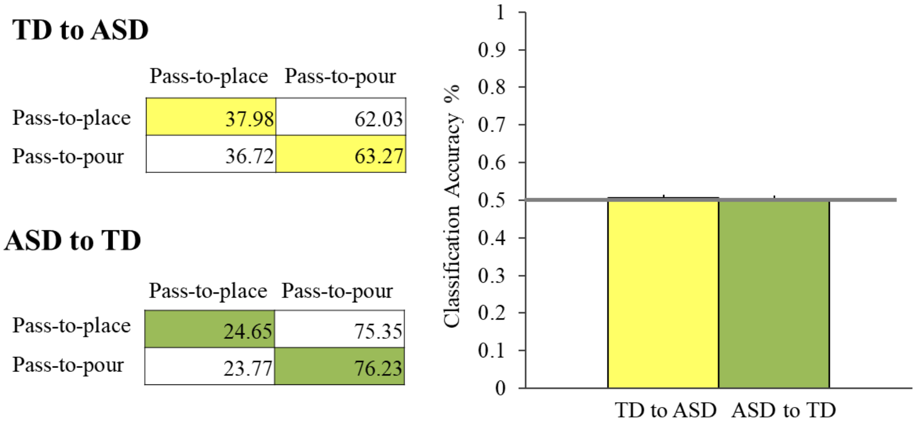


Figure 3.6. Discriminative power of kinematic features in TD (A) and ASD (B) group in prospective control of other-actions. The heatmaps show a graphical representation of Fisher scores of kinematic features over time. The higher the Fisher score, the greater the ability of a kinematic feature to discriminate between other-action plans. To allow comparison between groups, Fisher scores were normalized by dividing each score by the sum of all scores obtained in both groups.

Confirming this impression, cross-classification analysis was unsuccessful both when the classifier was trained on TD data and tested on ASD data (TD to ASD, M accuracy = .506, 95% CI = [.498, .515], empirical $p = 0.305$) and when it was trained on ASD data and tested on TD data (ASD to TD, M accuracy = .504, 95% CI = [.499, .510], empirical $p = 0.621$) (Figure 3.7).



TD to ASD

	Pass-to-place	Pass-to-pour
Pass-to-place	37.98	62.03
Pass-to-pour	36.72	63.27

ASD to TD

	Pass-to-place	Pass-to-pour
Pass-to-place	24.65	75.35
Pass-to-pour	23.77	76.23

Figure 3.7. Cross-classification results for prospective control of other-actions. Confusion matrices and classification accuracies for a SVM classifier trained on TD and tested on ASD group (TD to ASD) and for a SVM classifier trained on ASD and tested on TD group (ASD to TD). The classification accuracy did not exceed chance level (.50; grey horizontal line) in neither of the two cross-classifications. Error bars indicate standard error.

3.3.3 Idiosyncrasy of movement patterns

The reduced to absent kinematic modulation observed in the ASD group may stem from different phenomena at the single-subject level. First, the observed group effect may reflect increased noise in the motor system (Torres and Denisova 2016). Second, the effect may be due to a reduced degree of prospective control operating within each individual in the ASD group. Alternatively, it may reflect idiosyncrasies in the individual patterns of modulation, i.e., patterns that differ from one individual to another. On this account, the reduced pattern of modulation at the group level would result from misalignment of control strategies at the individual level causing a ‘regression to the mean effect’. In order to test this possibility, we trained SVM classifiers to distinguish place, pour and pass actions separately for each child in the TD and ASD group. Individual classification performance was computed using a leave-one-trial out cross-validation procedure and quantified as the resulting classification accuracy. Individual classification performance exceeded chance level (0.33) in both the TD group (M = .785, 95% CI= [.741, .829], t19 = 21.515, $p < 0.001$) and the ASD group (M = .755, 95% CI = [.700, .810], t19 = 16.229, $p < 0.001$). No difference was observed between ASD and TD children (t38 = -.891, $p = 0.378$), attesting comparable levels of modulation at the individual level (Figure 3.8). Notably, training SVM classifiers to distinguish pass-to-place and pass-to-pour actions separately for each child led to a similar pattern of results. Individual classification performance exceeded chance level (0.50) in both the TD group (M = .708, 95% CI= [.623, .792], t19 = 5.152, $p < 0.001$) and the ASD group (M = .618, 95% CI = [.517, .740], t19 = 2.016, $p < 0.05$), with no difference in classification accuracy between ASD and TD children; t38 = -1.270, $p = 0.218$). This indicates that the apparent absence of prospective motor control in anticipation of other-actions at the group level resulted entirely from misalignment of individual strategies.

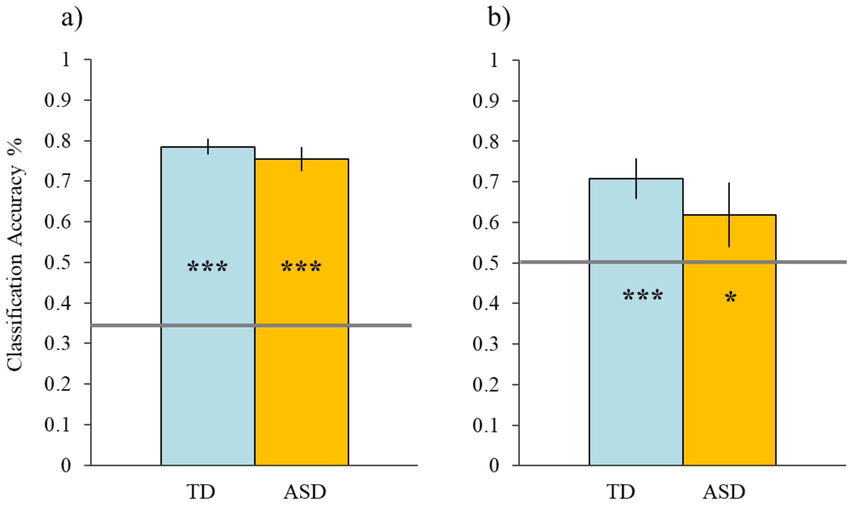


Figure 3.8. Individual classification performance for prospective control of self-actions (panel a) and other-actions (panel b). Classification accuracies obtained by averaging, separately for each group, results of 20 SVM classifiers (1 for each child). For prospective control of both self- (a) and other-actions (b), the classification accuracy exceeded chance level (grey horizontal lines) in both groups, with no significant differences between TD and ASD children. Asterisks inside bars indicate significant differences from chance level classification (*** = $p < 0.001$; * = $p < 0.05$). Error bars indicate standard error.

3.3.4 Relationship to symptoms and cognitive functions

To explore the possibility that prospective motor control in ASD is related to symptoms severity, we correlated self- and other-actions individual SVM classification accuracies with ADOS-2 and ADI-R total scores. Classification accuracies were also correlated with executive functions as measured by the Tower of London (TOL) test and with intelligent quotient as measured by the Full-Scale IQ. For each pair of variables, statistical significance was assessed with a non-parametric permutation test (1000 permutations). None of the correlations approached significance (p_s ranging from 0.178 to 0.834).

3.4 Discussion

We developed a multi-level classification strategy to comprehensively test the hypothesis of disturbances of prospective motor control in children with autism spectrum disorder. We found both similarities and dissimilarities in the prospective control strategies of ASD and TD children. For self-actions, although tailoring to the onward action was overall less pronounced in the ASD group than in the TD group, children in the two groups exhibited similar patterns of modulation. No such similarity was apparent for other-actions. Observing the heatmap in Figure 3.6, one might be inclined to conclude that the kinematics of the movements conducted by children with ASD did no show changes in anticipation of the actions of the partner. However, this conclusion overlooks the heterogeneity of autistic movement patterns. When analyzed at the individual-level, the kinematics of ASD and control children showed comparable levels of modulation for both self- and other-actions. This suggests that the reduced to absent modulation at the group-level resulted from misalignment of individual control strategies rather than from a lack of control strategies in individuals with ASD. Previous approaches investigating motor control in ASD only extrapolated group-level patterns, with limited success in capturing individual motor variability (Cattaneo et al. 2007; Fabbri-Destro et al. 2009; Scharoun and

Bryden 2016). A critical advance of our study is to show that group-level patterns can obscure the heterogeneity of individual strategies in motor control. The implication of this finding is that statistics that average ASD individual movement profiles within a group may fail to capture a distinctive trait of ASD motor performance. That possibly accounts for discrepant findings in previous studies. Future studies are necessary to understand the mechanisms that give rise to the idiosyncrasy of motor patterns. While there is a general consensus that individuality exists in motor patterns in both typical and atypical populations, how it arises and whether it reflects neural structure are still sources of debate (Ting et al. 2015). In the present study, we observed no correlation with diagnostic tests of ASD. This suggests distinct movement profiles within otherwise similar diagnostic profiles. It will be important for future studies to determine whether individual movement profiles correlate with individual differences in the function and organization of the cortical grasping network. Cattaneo and co-workers (2007) report failure of predictive muscle activation during execution of a sequential grasping task, although other studies (see Pascolo and Cattarinussi 2012) have recently failed to replicate this finding. Under the assumption that anticipatory muscle activation is an index of prospective motor control, we would expect the preparatory muscle activity to correlate with the degree of tailoring kinematics to the onward action at the individual level. Disturbances of development in systems that program timing, serial coordination and prospective control of movements have been proposed to be at the origin of social isolation, socio-emotional and cognitive delay in ASD (Trevarthen and Delafield-Butt 2013). Whilst the current results provide no direct evidence to support this idea, they indicate that children with ASD demonstrate divergent, idiosyncratic patterns in anticipation of others' actions. The consequences of this can be far-reaching. Kinematic similarity is thought to be important for the perception, prediction, and interpretation of others' movements (Cook 2016). Moving with different kinematics, typical and autistic individuals may experience reciprocal difficulties in social interaction. Moreover, because each atypical movement pattern is atypical in its own way, individuals with autism may also experience difficulties interacting with autistic partners whose movement patterns are dissimilar from their own. These predictions can be tested in future studies by investigating social interaction in TD-ASD and ASD-ASD dyads.

Chapter 4

Reading Intentions from Movements in Autism

4.1 Introduction

The behavior of others provides a rich source of information about the world around us. The capacity to extract and process this information is crucial for learning about the properties of objects acted upon, as well as to read others' intentions and expectations (Ansuini et al. 2015; Cavallo et al. 2016). In everyday life, objects can be grasped in several ways due to their properties (e.g., size, shape, weight), as well as to the action context and agent's intentions (see e.g., Ansuini et al. 2015).

Remarkably, body movement can represent a rich and reliable source of information. Importantly, it has been demonstrated that people are able to pick up and use kinematic information to judge what is going to happen next simply observing a movement flow (Abernethy et al. 2008; Manera et al. 2011; Sartori et al. 2011). Others' actions go beyond the 'here and now' of the action itself, manifesting, and potentially revealing, the future state of the action (Sparaci et al. 2015). It has been reported that typically developing (TD) children are able, from a very young age, to discriminate and gradually learn to make sense of other people's actions (Sparaci et al. 2014).

While understanding the mean of an action (i.e., how) and attributing intentions to the agent (i.e., why) may be an implicit and rather effortless task for TD individuals, several studies have found that people with ASD have great difficulty in doing so (Baron-Cohen 1985). Research in social neuroscience commonly distinguishes between mirror systems for comprehending biological motion and basic actions, and mentalizing brain systems for interpreting other people's beliefs and desires (Marsh and Hamilton 2011). However, recent evidence demonstrated that processing actions and intentions may not be mutually exclusive, with reliance on mirroring and mentalizing mechanisms mediating action understanding (Libero et al. 2014).

It is recently hypothesized that a failure in reading the intention underlying an agent's onward action might be one of the causes of profound social disabilities that characterize individuals with ASD (Cattaneo et al. 2007). Although autistic performance on action observation tasks requires further testing, some evidence have highlighted that children with ASD show difficulties in understanding other's action sequences (e.g., Cattaneo et al. 2007; Fabbri-Destro et al. 2009). In a well-known action observation study, Boria and colleagues (2009) required TD and ASD children to observe a picture of an action and to respond to specific questions i.e., '*why* is she doing it' or '*what* is she doing?'. Results indicated that autistic individuals made more errors on the 'why' questions than on the 'what' questions with respect to their cognitive functioning-matched peers (Boria et al. 2009). This result has been interpreted as speaking in favour of a deficit in the ability to read other's intention from movement observation. Further evidence was provided by Sparaci and colleagues (2014), who highlighted a significant difference among ASD and Williams Syndrome (WS) children. In an action observation task, authors showed that the understanding of the 'what' of an action was extremely difficult for WS compared to ASD individuals, who in turn did not differ from mental age matched controls (Sparaci et al. 2014). In contrast, when considering the understanding of the 'why' beyond the observed action, ASD and WS children performed similarly with more errors compared to their chronological and mental age matched peers.

Though there is evidence that ASD individuals may have difficulties in intention understanding from movement observation, these results are far from being conclusive because of limitations in: a) the control of other factors than the ASD diagnosis as FS IQ, executive functions, and verbal capabilities; b) the type of stimuli being used; c) the control of actual intention-related information available in movement kinematics. In this respect, many studies which have highlighted a deficit in action understanding in ASD had used non-realistic stimuli (i.e., meaningless movements, snapshots of hands detached from background) (e.g., in Boria et al. 2009), which are far from being good replica of the world due to a lack of the context of everyday-life situations (Amoruso et al. 2018). Indeed, although it has been claimed that a failure in understanding other's intentions in ASD may stem from a difficult in extracting motor cues of other's movements (Boria et al. 2009), previous researches did not demonstrate whether information about intentions was actually encoded in motor pattern. Thus, it is unclear whether participants with ASD did not understand the intention from movement observation due to other's intention 'blindness' or either to a lack in the availability of motor information itself.

To cope with these limitations, we asked 19 children with a clinical diagnosis of ASD and 17 TD children matched for age, handedness, and FS IQ to take part to an action observation study. In order to assess TD and ASD children ability to understand other's mental states simply observing a movement flow, we selected video-clips to show so to ensure that intention-relation information was available in the observed movements. Furthermore, to test whether children would be better at discerning intentions from movements that are similar to their own group, each participant was presented with randomly video-clips of actual movements performed by both ASD and TD children.

4.2 Materials and methods

4.2.1 Participants

We recruited 19 children with Autism Spectrum Disorder without accompanying intellectual impairment (ASD group: 17 males) and 17 age-matched typically developing children (TD group: 13 males). Children from both groups were recruited from the Child Neuropsychiatry Unit of the 'Giannina Gaslini' Hospital and schools in Genova. All participants had normal or corrected-to-normal vision and were screened for exclusion criteria (dyslexia, epilepsy, and any other neurological or psychiatric conditions). Groups were matched for age (TD M ± SD = 10.2 ± 1.2 years.months; ASD M

± SD = 10.5 ± 1.4 years.months; t34 = .686, *p* = 0.497) and Full Scale IQ as measured by the Wechsler Scale of Intelligence (WISC IV) (TD M ± SD = 104.2 ± 9.1; ASD M ± SD = 98.7 ± 11.3; t34 = - 1.607, *p* = 0.117). All but two of the children (one in the ASD group and one in the TD group) were right-handed according to the Edinburgh Handedness Inventory (Oldfield 1971).

4.2.2 Stimuli and procedure

To create the stimuli to-be-used in the action observation experiment, we filmed 20 children with ASD and 20 TD children performing reach-to-grasp movements towards a bottle filled with water in order to place it in a box (i.e., to place) or to pour the water into a glass (i.e., to pour). Reach-to-grasp movements were captured from a lateral viewpoint using a digital video camera (Sony Handycam 3D, 25 frames/s; Sony Corporation, Tokyo, Japan). To assess the availability of intention information over time, a set of kinematic variables was calculated using a custom Matlab (MathWorks, Natick, MA, USA) script. All variables were computed only considering the reach-to-grasp phase of the movement, i.e., from 'reach onset' (i.e., the first time point at which the wrist velocity crossed a 20 mm/s threshold and remained above it for longer than 100 ms) to 'reach offset' (i.e., the time at which the wrist velocity dropped below a 20 mm/s threshold) at an interval of 10% of the normalized movement time (see Ansuini et al. 2016) included:

- wrist velocity, defined as the module of the velocity of the wrist marker (mm/sec);
- wrist height, defined as the z-component of the wrist marker (mm);
- grip aperture, defined as the distance between the marker that was placed on the tip of the thumb and the marker placed on the tip of the index finger (mm).

To better characterize hand movements at the joint level, the second set of features was expressed with respect to a local frame of reference centered on the hand (i.e., F_{local}; see Caterina et al. 2015 for a detailed description of this frame of reference). This set of features included:

- x-, y-, and z-thumb, defined as x-, y- and z-coordinates for the thumb (mm);
- x-, y-, and z-index, defined as x-, y- and z-coordinates for the index finger (mm);

With respect to the stimulus selection, we proceeded as follows: first, we submitted the computed kinematic variables to separate linear discriminant analyses (LDAs) to find the linear combinations of features that, for each group, best separated between placing and pouring reach-to-grasp movements. If the kinematic features are informative about the intentions, then a high classification score is achieved. LDAs using a leave-one-out cross validation method revealed that classification of the two intentions was significantly above chance level (i.e., 50%) for both placing and pouring grasping movements in both groups (see Table 4.1 in Appendix B for LDAs results for placing and pouring grasping movements separately for TD and ASD group). Then, based on LDA results, we selected the 25 more prototypical movements for each intention (placing vs. pouring) that minimized the distance from their own centroid.

Participants were required to watch video clips and identify as accurately as possible if a model’s hand reached and grasped the bottle to either place it within a container or pour its content into a glass. Responses were given by pressing one of the two response buttons on a response box. For half of the participants, the Italian word ‘Mettere’ (i.e., to place) on the left prompted a button press with thumb finger of the left hand on the left button of a response box, while the word ‘Versare’ (i.e., to pour) on the right prompted a button on the right button press using the thumb index of the right hand. The position of the two words was counterbalanced across participants. This first black screen was followed by a white fixation cross (+) at the centre of the monitor for 1000 ms. Then, a video-clip showing the reach-to-grasp phase of the action was presented. The duration of the videos, which varied according to the actual duration of the movement (M = 878.7; SE = 20.5; range = 540 ms – 1720 ms), did not differ between intentions both for ASD movements (t48 = -.006; $p > 0.05$; Place: M = 865.2; SE = 41.3; Pour: M = 865.6; SE = 52.2) and TD movements (t48 = -1.173; $p > 0.05$; Place: M = 863.2; SE = 35.9; Pour: M = 920.8; SE = 33.5).

To ensure that movement sequences could be temporally attended (i.e., to provide participants enough time to focus on movement start), +4 to +20 static frames, in step of 2 were randomly added at the beginning of each video clip (see Figure 4.1 for a representation of each experimental trial).

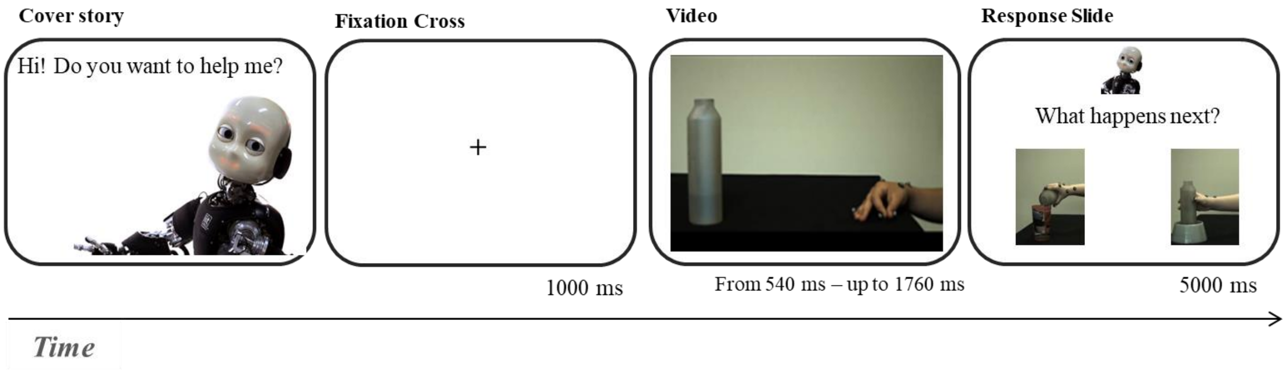


Figure 4.1. Illustration of an experimental trial. Each trial started with fixation cross, followed by the video clip of a reach-to-grasp movement. Participants were required to respond after each video clip within the subsequent 5000-ms response interval.

Participants were instructed to respond correctly and as quickly as possible. They were not allowed to give their response during the video clip, but after the end of video clip within the subsequent 5000-ms response interval. No feedback was provided to the participants at any stage of the experiment.

At the beginning of the experiment, participants were presented with two sample movements within the action execution experimental setup, so that they could even see the phase during which the agent poured the water into the glass or place the bottle into a container. Further, before starting the experiment participants performed a small practice which consists in 5 video clips each for the intentions performed by either TD and ASD children. Video-clips were administered in two separate blocks, one for each type of observed movements i.e., performed by either TD and ASD children. In each block, videos for both intentions (i.e., 25 for pouring intentions, 25 for placing intentions) were randomly presented. At the end of the experimental session, each child was asked to fulfil a very short interview. Stimuli presentation, timing, and randomization procedures were controlled using E-prime version 2.0.10.242 (Psychology Software Tools, Inc, Sharpsburg, PA, USA).

4.2.3 Data analyses

Signal Detection Theory (SDT) was used to analyse intention judgments parameters. We calculated *d prime (d')*, which provides a measure of the distance between the signal (i.e., arbitrarily defined as placing intention) and the noise means (i.e., arbitrarily defined as pouring intention) in standard deviation units (Stanislaw and Todorov 1999). To establish whether children's ability to identify placing and pouring intentions was above chance level (0), d' values were submitted to one-sample t-tests. Furthermore, an Analysis of Variance (ANOVA) with type of observed video (TD movements, ASD movements) as within-subjects factor, and group (TD, ASD) as between-subjects factor was performed on d' values. To capture the relationship between reading intention ability, cognitive functioning and autistic symptoms severity, we correlated (by means of Pearson's correlation) d' values with FS IQ and ADOS-2 scores.

4.3 Results

Participants' responses whose reaction times (RTs) deviated more than 3 SD were treated as outliers and removed from further analyses. Results from one tailed t-tests on d' values indicated that TD children were able to read the intention leading the observed action. This was evident when they observed movements performed by both TD group (t16 = 1.902; $p = 0.037$) and ASD group (t16 = 1.978; $p = 0.032$). In contrast, when considering ASD children performance, t-test revealed that they lacked the ability to correctly identify the intention from the observation of both groups' movements (TD movements: t18 = -1.596; $p = 0.064$; ASD movements: t18 = -.487; $p = 0.316$) (see Figure 4.2).

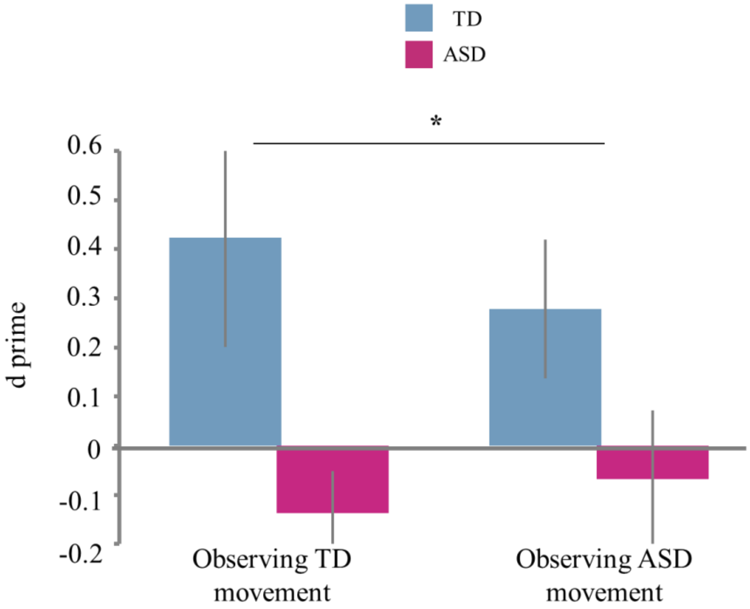


Figure 4.2. Graphic representation of results from one-sample t-tests on d' values. The ability to accurately identify the intention from observed movements was above chance level in TD children (in blue), but not in ASD children (in purple). Error bar indicates standard error. Asterisks indicate significant differences from chance level classification (test value = 0) (* = $p < 0.05$). Vertical lines represent standard errors.

Furthermore, this scenario was confirmed by ANOVA on d' values. We found a main effect of group (F1, 34 = 6.456; $p = 0.016$; $\eta^2 = 0.160$). Post-hoc contrasts indicated that TD children performed more accurately than ASD children in identifying placing and pouring intentions from observed movements (M ± SE = .351 ± .130 vs. = -.103 ± .123, for TD and ASD children, respectively).

The correlation analysis revealed no significant relationship between d' values and FS IQ ($p_s >$ 0.137). Neither the association between d' values and the degree of autistic severity was significant

(ADOS-2 Total Score: $p_s > 0.396$; ADOS-2 Social Affect: $p_s > 0.269$; ADOS-2 Restricted and Repetitive Behaviors: $p_s > 0.570$).

4.4 Discussion

Difficulties in understanding and predicting others' actions, as well as difficulties in higher mind functions, are frequently reported in children with autism (Delafield-Butt and Trevarthen 2017). Given that the understanding of others' actions plays a crucial role in scaffolding social interactions, the aim of this action observation study was to investigate ASD children' ability to read the prior-intention behind the observed grasping movements. TD children demonstrated an enhanced ability to correctly identify different intentions simply observing others' movements. This was evident not only when observing movements from children with a similar developmental profile, but also when movements were performed by ASD children. In contrast, autistic children were not able to understand whether an observed reach-to-grasp movement towards a bottle was performed with the intent to place it or to pour the water into a glass and this difficulty was evident regardless the movement was performed by a TD or an ASD children. Here below these results are discussed in light of recent studies which explored the intention understanding from observed movements in individuals with autism.

It has been hypothesized that a failure in reading other's intentions in ASD may stem from a reduced prospective control in terms of an anticipation of other's forthcoming acts, when relying exclusively on motor cues (Boria et al. 2009; Gowen 2012). The observation of a hand grasping an object provides to an observer two different types of intention information: a) motor information, based on the observed hand-object interaction; and b) functional information, based on the typical use of the object (Boria et al. 2009). Boria and colleagues (2009) suggested that the increased error rates indicate that, unlike TD children, children with ASD were not able to process the motor information from the agent's hand shape. Thus, they based their response about agent's intention mainly on the functional information of the object (e.g., a pair of scissors and sheets of paper). On the contrary, other studies suggest that a general deficit in mentalizing function, rather than a specific difficult in using others' motor information, might be likely related to difficulties in intentions understanding in ASD. Sparaci and colleagues (2014) highlighted a significant difference among ASD and Williams Syndrome (WS), showing that the understanding of the 'what' of an action was extremely difficult for WS children, while ASD children did not differ from mental age-matched controls (Sparaci et al. 2014). When no additional contextual cues were provided, results showed no difference between the ASD and WS groups in why understanding. Both groups performed in a similar way showing more errors than chronological and mental-age matched peers. However, in presence of contextual cues (e.g., a box into put a piece of puzzle), difficulties in why understanding were greatly reduced in both ASD and WS groups, and both clinical groups made as many errors as chronological and mental age matched controls (Sparaci et al. 2014). Since for TD children errors in the 'why' task diminish as chronological and mental age grow, interestingly, within the ASD group, errors in the 'why' task showed a negative correlation with mental age, but not with chronological age. Authors suggest that children with ASD may attempt a more 'cognitive' interpretation of others' actions, which does not rely on motor information (Sparaci et al. 2014).

However, these studies that have claimed a failure in understanding other's intentions in ASD did not demonstrate whether information about intentions was actually encoded in observed motor patterns. Whether and how observers can detect intention seems to be negligible. A critical advance of our study is to show that, despite linear discriminant analyses (LDA) results probe that kinematic information was available in movements performed by both TD and ASD group, children with ASD lack the necessary attunement to pick up the available intention information. On the contrary, TD children extract and use this kinematic information to correctly identify different intentions. Results from LDAs indicated that the kinematic variables that contributed the most to intention classification were wrist height and thumb finger vertical displacement in both TD and ASD children. Children from both groups show a similar modulation with respect to different intentions, reflecting that even individuals with ASD adjusted their movements in accommodation of prior-intentions.

Neuroimaging studies may help to shed light on neural underpinnings of action observation in autism. Given the consistent findings of abnormal Mentalizing Network (MZN) in ASD (Hamilton et al. 2007; Hamilton 2013; Kana et al. 2014), one would expect an atypical recruitment of the MZN network while attending to intentions, but rather a typical Action Observation Network (AON) activation when processing the means of an action in ASD participants. However, recent studies showed that processing actions and intentions may not be mutually exclusive, with reliance on mirroring and mentalizing mechanisms mediating action understanding (Libero et al. 2014). Indeed, AON and MZN may be involved at different levels within the action hierarchy, with the AON encoding what action is being performed, how it is being performed, and what the immediate predicted outcome of the action is, while the MZN encodes why an action may be performed from the perspective of the performer (Catmur 2015; Spunt et al. 2011). While STS/TPJ and IFG belong to seemingly different, anatomically segregated networks (MZN and AON respectively), their functional communication may be important in understanding actions at richer and more comprehensive levels. In this respect, Libero and colleagues (2014) demonstrated that healthy adults seem to be effectively engaging and coordinating frontal and temporal regions in processing actions at multiple levels (i.e., perceptual, motor, goal-oriented or intentional). This is corroborated by further recent findings showing that rather than simply being sensitive to biological stimuli, it is now recognized that the AON also responds to non-biological stimuli if preceded by primes that influence belief or social belonging, and thus recruiting the MZN (Roberts et al. 2014). Moreover, it has been suggested that the evidence that the AON is active during the observation of non-human agents like humanoid robots may reflect an ascription of human properties such as mental states to these agents (Chaminade and Cheng 2009).

Although results of our study did not allow us to draw conclusion about neural underpinning supporting action observation, a possible speculation is that, given availability of kinematic information in observed motor patterns, such atypical ‘communication’ between different areas involved in action processing may contribute to the failure in reading other’s intention from observed movements in ASD children.

An alternative possible explanation considers the alteration of perceptual organization. Interestingly, individuals with a diagnosis of autism have been commonly described as ‘seeing the trees, but not the forest’. Indeed, experimental evidence indicates that they tend to attune to single details of the perceptual world, rather than to have a comprehensive representation of all particulars. One possibility is that perceptual representation in autism exhibits a bias towards local over global features of a sensory scene, which can be more or less advantageous depending on task demands (Robertson and Baron-Cohen 2017). One speculation is that this may particularly affect global motion perception. Anyway, further researches are needed to clarify this issue.

Despite both groups exhibited a similar patterns of intention modulation, ASD children show a marked difficult in understanding other’s intention (regardless of which group performed the observed movements) compared to TD children, who in turn correctly identify intentions from the observation of movements performed by either TD and ASD. This may be in contradiction with the hypothesis that individuals with autism might develop a visual system that is tuned to atypical representations of biological motion from observing their own atypical actions (Cook et al. 2013). Indeed, in our study children with ASD did not move in such atypical way. Since several studies show that when observed movements fall within the observer’s own motor repertoires, action prediction is greater (Aglioti et al. 2008), one should expect that, even when required to discern intentions from movement which they are familiar, both ASD and TD perform at the same level. To date, there is a general consensus that heterogeneity is a consistent finding in autism research and has been proposed to reflect a distinctive characteristic of neural activity in ASD (Hahamy et al. 2015; Ting et al. 2015). However, while the task design does not permit to draw conclusion, one might be inclined to speculate that an additional factor that may account for modulation of reading intention ability is the great variability in autistic individual responses. Nevertheless, the role played by movements from individuals with a similar developmental profile on action understanding is still unclear and need further investigation.

Chapter 5

Conclusion and Future Works

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder defined by primary deficits in social interaction and communication and restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association 2013). Beside core deficits in social interaction and communication, atypical motor patterns have been often reported in people with ASD (Gowen and Hamilton 2013). It has been recently speculated that a part of these sensorimotor abnormalities could be better explained taking into account of prospective motor control (i.e., the ability to plan actions toward future events or consider future task demands), which has been hypothesized to be crucial for higher mind functions (e.g., understand intentions of other people) (Trevarthen and Delafield-Butt 2013). However, current findings are mixed and puzzling potentially because of heterogeneity in individual motor strategies of people with autism. In the current thesis, I adopted a multimodal and integrated approach to investigate prospective motor control capabilities in children with autism.

In the first experiment, the grasp height effect (Rosenbaum et al. 2012), defined as a window into prospective sensorimotor control, was found to a similar degree in autistic and typically developing (TD) children group. Findings from this study also demonstrated that intellectual functioning level (as measured by FS IQ) might play a role in the ability to disengage from automatic motor patterns and control an action flexibly and prospectively. Studies exploring prospective control in ASD produced highly mixed results, with as many studies reporting impairments in children with ASD (Hughes 1996; Scharoun and Bryden 2016) as those finding no significant group differences (Gonzalez et al. 2011; Hamilton et al. 2007; van Swieten et al. 2010). In this first study, however, only a single ‘spatial’ measure, that is the grasp height, was tested. Given that an important aspect of prospective planning concerns the spatiotemporal patterning of an action sequence (e.g., when the hand starts to adjust to future acts), in the second experiment, the kinematic unfolding of reach-to-grasp movement as captured throughout the entire action sequence was considered. Results from group-level analyses indicated that, for self-actions, children in the two groups adjusted their movements with respect of what they plan to do next. However, no such similarity was apparent for other-actions. When analysed at the individual-level, the kinematics of ASD and TD children showed a modulation to a similar extent not only for self-actions, but also for other-actions. Our results indicated that group-level patterns can obscure the heterogeneity of individual strategies in motor control. Consequently, the implication of this finding is that traditional statistics that average ASD individual movement profiles within a group may fail to capture a distinctive trait of autistic motor performance (see e.g., Cattaneo et al. 2007; Fabbri-Destro et al. 2009). Furthermore, given that difficulties in understanding and predicting others' actions, as well as difficulties in higher mind functions, are frequently reported in children with autism (Trevarthen and Delafield-Butt 2013), the aim of the third experiment was to assess whether autistic children were able to 'translate' this kinematic modulation for self and other's action into the ability to read other's intention simply observing a movement flow. Findings indicated that, while TD children demonstrated an enhanced ability to correctly identify different intentions beyond others' movements, ASD children were not able to read the intention from the observation of others' motor behaviors. Although previous studies have reported a failure in understanding other's intentions in ASD due to a difficult in extracting motor cues from other's movements (Boria et al. 2009) or either to poor mentalizing functions (Sparaci et al. 2014), they did not demonstrate whether information about intentions was actually encoded in motor pattern. Here, having demonstrated that kinematic information about intention was still available in both TD and ASD movements, one might conclude that children with ASD lack the necessary attunement to pick up intention information to understand other's behavior.

Taken all together, these findings challenge the hypothesis of a general prospective sensorimotor control deficit in autism and suggest that not all motor control processes are impaired in individuals with ASD (Gowen and Hamilton 2013). Furthermore, caution is needed when applying traditional group-level statistics because they may hardly capture actual sensorimotor capability in ASD.

However, some issues are still unclear and need further investigation:

1. While motor impairments in ASD have been reported by common used and standardized tests, such as MABC-2, several experimental tasks highlighted a preserved motor control. Thus, it is often hard to know which specific motor processes are abnormal in autism. A possible speculation is that, although test batteries distinguish ‘fine’ from ‘gross’ motor skills, they do not relate closely to the underlying specific motor mechanisms, such as integration across different sensory information and prediction of sensory consequences of movement (Gowen and Hamilton 2013).

2. Although one might conclude that ASD children fail in processing actions at multiple levels (i.e., perceptual, motor, goal-oriented or intentional), it is still unclear the exact nature of this impairment. Some authors indicate that ASD participants struggle to identify ‘typical’ biological motion (Cook et al. 2013) and that, when required to describe actions performed by point-light actors, they lacked in the ability to perceive and categorize biological typical motions (Hubert et al. 2007). However, others suggested that autistic people were able to adequately process various aspect of biological motion (e.g., from the basic ability to distinguish biological from non-biological motion to the capacity to discriminate a dancing action from a fighting action) (Cusack et al. 2015). Given that the role of mirror neuron system (MNS) is still debating, future neuroimaging studies are needed to examine the anatomical and functional roles of Action Observation Network (AON) and Mentalizing Network (MZN) in action understanding and social cognition in autism.

3. The majority of studies which investigated prospective motor control tested high-functioning children with autism. The risk is that experimental tasks could not be feasible to children with lower

cognitive functioning and/or non-verbal individuals. And so, it is reasonable to infer that these findings could not be generalized to all children in the autistic spectrum.

Possible interventions and new-technologies implication

Although current results did not have direct therapeutic implications, they provide some critical leads for autism research in the clinical field. In order to provide the best services for children with ASD, therapists must be aware of child's motor strengths and weaknesses. It is generally recognized that the most effective clinical route to treatment is its early identification and consequent early therapeutic intervention. It has been demonstrated that a significant proportion of children receiving intensive intervention early in life make outstanding progress, with significant gains in cognition, language, and adaptive behavior (Elder et al. 2017).

Given that clinical assessment of motor skills is commonly administered by test, such as the MABC-2, which may lack of precise quantification of motor skills, there are several technological solutions available to investigate infants' motor behavior, such as stereo-photogrammetric movement analysis systems, gaze-tracking devices, and force platforms. The approach described in this dissertation consists in the use of near-infrared motion capture system with passive markers. Such an approach, besides being very expensive, requires a highly structured environment (i.e., laboratories), that could intimidate children with ASD. The need to provide more accessible and more precise computational measures of motor performance for clinical assessment and research lead to the development of non-obtrusive technology (e.g., being small in size, lightweight, wireless and portable) that can be used in minimally structured and ecological environments by means of inertial motion sensors, gyroscopes and magnetometers. These novel devices, already present in smartphones, tablets, and in wearable devices, such as smart watches and wristbands, provide unique access to motor information (see e.g., Taffoni et al. 2014).

The key idea is that a motor perspective on social impairment in people with ASD could promote new intervention strategies aimed at improving those interactions, from early imitation to joint actions, which may foster the development of social skills. The adoption of experimental paradigms investigating movement not in ‘isolation’, but in ‘real-time’ social interactions (Schilbach et al. 2013) could allow a deeper understanding of the link between motor and social skills in atypical and typical development. Latest behavioral findings suggest that in typically developing children, the perception of biological movements and social cognitive abilities are tightly linked, and therefore, during development, the perceptual system for analyzing biological motions might be functionally integrated with social abilities (Pavlova 2012). However, whether ASD children experience difficulties in processing biological motions is still matter of debate. Autistic adolescents with impaired high-level symbolic processing can reliably differentiate point-light human actions from similar moving configurations of inanimate objects (Moore et al. 1997). Experimental evidence found that ASD young adults are impaired on detection of the direction of a point-light walker embedded in a coherent motion mask (Koldewyn et al. 2011), although they perform similar to typically developing controls on a static coherent form task and on a coherent motion task. In order to shed light on this puzzling scenario, a possible speculation concerns the suggestion of a novel sensorimotor approach to therapeutic intervention. The proposed intervention strategy should aim to exploit the potential of ‘modularity of control’ of humanoid robots, which allows to copy specific (e.g., autistic or non-autistic, biological or not biological) kinematic features into the robot’s movement (an impossible endeavour for a human) (Sciutti and Sandini 2017; Wykowska et al. 2016). This might promote attunement to the observed movements.

Appendix A

Neuropsychological Assessment

Previous studies that have sought to examine which aspect of motor skill may be impaired in children with ASD have yielded conflicting results. There are several possible causes for these discrepancies, including differences not only between the task and procedures, but also in the sample size and age of participants, as well as their cognitive and motor development. All of this making comparison across results difficult. Our studies tried to rectify these limitations in this way. Skilled professionals (i.e., a child neuropsychiatrist and a neuropsychologist) administered a set of neuropsychological tests to gather detailed information about children's language, motor and executive functions. Participants who took part to studies described specifically in Chapter 2, Chapter 3 and Chapter 4 were matched for age, stature, handedness, and cognitive functioning.

Children in the ASD group, diagnosed according to DSM-5 (American Psychiatric Association 2013) norms, met cut-off criteria for ASD with respect to the total score obtained at the Autism Diagnostic Observation Scale-2 (ADOS-2; Lord et al. 2012) and the Autism Diagnostic Interview-Revised (ADI-R; Rutter et al. 2003). The ADOS-2 is a semi-structured assessment of communication, social interaction, and play (or imaginative use of materials) for individuals suspected of having autism or other pervasive developmental disorders. The ADOS-2 comprises five modules, each designed to be appropriate for children and adults with different expressive language level and chronological age. This test includes structured activities and materials that allow the examiner to observe the occurrence or non-occurrence of those behaviors that have been identified as important to the diagnosis of autism. The ADI-R is a structured interview conducted with the parents of individuals with a mental age of at least 18 months. The ADI-R provides critical information in the areas of reciprocal social interaction, communication and language, and patterns of behavior. The interview is divided into five sections: opening questions, communication questions, social development and play questions, repetitive and restricted behavior questions, and questions about general behavior problems.

To assess cognitive functioning, each participant was administered with the Wechsler Intelligence Scale for Children-IV (WISC-IV; Wechsler 2003). Given a measure of intellectual performance as a multidimensional construct, the WISC-IV contains 10 core subtests and 5 additional subtests. These are summed to four indexes, i.e., the Verbal Comprehension Index (VCI), the Perceptual Reasoning Index (PRI), the Working Memory Index (WMI) and the Processing Speed Index (PSI) and a Full Scale IQ (FS IQ). The FS-IQ, ranging from lowest 40 to highest 160 points, is computed from a combination of ten core subtest scores and is considered the most representative measure of global intellectual functioning. The other four indexes consist in the following sub-tests:

- VCI: Vocabulary, Comprehension, Similarities, Information[3]*, Word reasoning*;
- PRI: Picture Concepts, Block Design, Matrix reasoning, Picture completion*;
- WMI: Digit Span, Letter-Number Sequencing, Arithmetic*;
- PSI: Symbol search, Coding-Digit Symbol, Cancellation*.

Apart from providing IQ scores, the WISC-IV also offers subtle and critical clinical insights into a child's strengths and weaknesses.

Furthermore, with respect to experiment aim, every child both from TD and ASD groups could be tested on the following motor and cognitive tests:

- Movement Assessment Battery for Children (MABC-2). The MABC-2 (Henderson et al. 2007) is a validated measure of movement skill in children, spanning from fine (e.g., manual dexterity) to

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[3] Asterisks indicate supplementary sub-tests.

gross motor skills (e.g., walking, balance, jumping), encompassing a number of different processes relating to sensory, planning and execution aspects of motor control. The MABC-2 is divided into three age bands, each designed to be suitable for a specific age group of children: 3 to 6 years, 7 to 10 years, and 11 to 16 years. This test battery comprises three different subtests that test manual dexterity, ball skill and static and dynamic balance. Percentile scores can be used as an indicator of motor difficulties, with scores below the 5th percentile suggesting a significant motor difficulty (red zone), between the 6th and 15th percentiles signifying a borderline motor difficulty (amber zone), and above the 15th percentile indicating no motor difficulty (green zone);

- Tower of London Test (TOL). The TOL test (Anderson et al. 1996), originally developed by Shallice (1983), is a widely used neuropsychological test of executive planning and problem solving. The TOL test materials include two identical tower structures (i.e., one for the child and one for the examiner) of three wooden pegs of descending heights, mounted on a block base. Three beads (red, green, and blue) are placed on the pegs in given start position. Subjects are required to replicate, on their own tower structure, the different problem configurations presented on the examiner's tower structure in as few moves as possible, while adhering to specific rules (Culbertson and Zillmer 1998);
- Peabody Picture Vocabulary Test-Revised (PPVT-R). The PPVT-R (Dunn and Dunn 1997; for Italian standardization, Stella et al. 2000) was used to assess children's receptive vocabulary. The PPVT-R consists of 175 stimulus words and 175 corresponding image plates. Each image plate contains 4 black-and-white drawings, one of which best represents the meaning of the corresponding stimulus word. The first item, or starting point, is determined based on the child's PPVT age. A child's raw score is determined by adding the number of correct responses between the lowest basal (i.e., when a child correctly identifies eight consecutive items) and the highest ceiling item (i.e., when a child incorrectly identifies six of eight consecutive items). PPVT-R results can be reported as age-based scores (with a mean of 100 and a standard deviation of 15) that range from 20 to 160.

For all children, parental written informed consent was obtained. Studies were approved by the local ethics committee (ASL3 Genovese) and performed in accordance with the principles of the revised Helsinki Declaration (World Medical Association General Assembly 2008).

Appendix B

Chapter 2

Table 2.1

ADOS-2 and ADI-R scores for participants in the ASD group.

	ADOS-2			ADI-R				
Participant	Total Score	SA	RRB	Total Score	A)	B)	C)	D)
1	*8*	6	2	30	*12*	*9*	*7*	*2*
2	*8*	6	2	28	*10*	*11*	*5*	*2*
3	*9*	8	1	25	*10*	*8*	*5*	*2*
4	*8*	6	2	28	*11*	*9*	*4*	*4*
5	*8*	7	1	31	8	17	*5*	*1*
6	*8*	7	1	49	*20*	*15*	*10*	*4*
7	*13*	11	2	21	9	*8*	*3*	*1*
8	*9*	8	1	41	*18*	*19*	*3*	*1*
9	*8*	7	1	30	*11*	*11*	*5*	*3*
10	*8*	7	1	24	*10*	*8*	*5*	*1*
11	*10*	8	2	29	*11*	*8*	*5*	*5*
12	*9*	8	1	32	*12*	*11*	*6*	*3*
13	*8*	7	1	24	*10*	*9*	*4*	*1*
14	*9*	8	1	24	*10*	7	*6*	*2*
15	*8*	7	1	25	*11*	*9*	*3*	*2*
16	*8*	6	2	24	*10*	5	*7*	*2*
17	*7*	6	1	27	*14*	3	*6*	*4*

Note. ADOS-2 (Autism Diagnostic Observation Scale 2) subtests: SA (Social Affect); RRB (Restricted and Repetitive Behaviors). Cut-off score for ADOS-2 Total Score (SA + RRB): (autism = 9; autism spectrum= 7). ADOS-2 Total score range (0-28). ADI-R (Autism Diagnostic Interview-Revised) subtests: A) Qualitative Abnormalities in Reciprocal Social Interaction (cut-off score = 10); B) Qualitative Abnormalities in Communication (cut-off score = 8); C) Restricted, Repetitive, and Stereotyped Patterns of Behavior (cut-off score = 3); D) Abnormality of Development Evident at or Before 36 Months (cut-off score = 1). ADI-R Total score range (0-78). The scores in Italics meet cut-off criteria.

Table 2.2

Summary of ASD and TD group characteristics and Full Scale IQ.

	Group	Mean	SD	Min	Max
Age (years.month)	ASD	9.9	1.6	7.1	12.9
	TD	9.5	1.5	7.1	12.5
Stature (centimetre)	ASD	141.2	8.7	126	156
	TD	138	9.1	122	160
Full Scale IQ	ASD	96.3	10.2	81	113
	TD	102.8	9.4	83	115

Note. ASD = Autism Spectrum Disorder; TD = Typically Developing; Total standard scores reported for Full Scale IQ M = mean; SD = standard deviation; Min = Minimum; Max = Maximum.

Table 2.3

Motor and cognitive details for participants in ASD and TD group.

		MABC-2				PPVT-R	TOL
Participant	Group	Total Score	Manual Dexterity	Ball Skills	Balance		
1	ASD	*4*	*<15*	>15	>15	110	30
2	ASD	70	>15	>15	>15	106	90
3	ASD	36	*<15*	>15	>15	103	85
4	ASD	*1*	*<15*	*<15*	*<15*	*82*	65
5	ASD	*1*	*<15*	>15	*<15*	103	65
6	ASD	*1*	*<15*	>15	*<15*	110	30
7	ASD	*6*	*<15*	>15	>15	106	95
8	ASD	*2*	*<15*	*<15*	>15	103	40
9	ASD	29	*<15*	>15	>15	106	90
10	ASD	*13*	>15	*<15*	>15	100	35
11	ASD	*1*	*<15*	*<15*	*<15*	*84*	75
12	ASD	36	>15	>15	>15	106	*15*
13	ASD	18	*<15*	>15	>15	*72*	40
14	ASD	40	*<15*	>15	>15	100	65
15	ASD	*1*	*<15*	*<15*	*<15*	*84*	90
16	ASD	*1*	*<15*	*<15*	>15	100	80
17	ASD	*1*	*<15*	*<15*	*<15*	*77*	90

		MABC-2				PPVT-R	TOL
Participant	Group	Total Score	Manual Dexterity	Ball Skills	Balance		
1	TD	65	>15	>15	>15	98	90
2	TD	*13*	>15	*<15*	>15	104	65
3	TD	18	*<15*	>15	>15	107	95
4	TD	*3*	*<15*	>15	>15	124	95
5	TD	18	*<15*	>15	>15	115	95
6	TD	29	*<15*	>15	>15	99	60
7	TD	*1*	*<15*	*<15*	*<15*	107	*15*
8	TD	*5*	*<15*	>15	>15	123	95
9	TD	45	*<15*	>15	>15	100	25
10	TD	45	*<15*	>15	>15	125	60
11	TD	36	*<15*	>15	>15	118	70
12	TD	*11*	*<15*	>15	>15	110	85
13	TD	40	*<15*	>15	>15	109	85
14	TD	65	>15	>15	>15	108	90
15	TD	36	>15	>15	>15	122	60
16	TD	45	*<15*	>15	>15	122	75
17	TD	65	>15	>15	>15	*75*	55
18	TD	16	*<15*	>15	>15	107	30
19	TD	45	*<15*	>15	>15	*84*	60
20	TD	36	*<15*	>15	>15	93	*5*

Note. ASD = Autism Spectrum Disorder; TD = Typically Developing; Percentile intervals reported for MABC-2 (Movement Assessment Battery for Children-2; cut-off at the 15th percentile); Total standard scores reported for PPVT-R (Peabody Picture Vocabulary Test-Revised; cut-off at the standard score of 85 or lower, i.e., 1 or more SDs below age-based corrected normative data); Percentile values reported for TOL (Tower of London; cut-off at the 15th percentile). Scores meeting cutoff criteria are reported in *Italics.*

Table 2.4

Height information for home and target positions.

ASD participants (N)	TD participants (N)	Stature Range (centimetre)	Height of Home Position (centimetre)	Height of Target Position		
				Low	Middle	High
1	3	120-129	55	40	60	80
7	7	130-139	64	50	70	90
5	8	140-149	73	60	80	100
4	2	150-160	80	70	90	110

Note. Heights are expressed with respect to the floor (centimetre).

Chapter 3

SVM Model

SVM is a non-probabilistic kernel-based decision machine that leads to a sparse solution. This implies that predictions for new inputs depend only on the kernel function evaluated at a subset of the training data points, called *support vectors*. The determination of the model parameters corresponds to a convex optimization problem, and so any local solution coincides with a global optimum. These properties allow to reduce the computational time while increasing the algorithm performance. SVMs have been used for solving object recognition tasks (Blanz et al. 1996; Chapelle et al. 1999; Schölkopf et al. 1996), regression and time series prediction applications (Drucker et al. 1997; Muller et al. 1997; Stitson et al. 1999), and novelty detection problems (Gardner et al. 2006; Hoffmann 2007; Schölkopf et al. 1999).

Given the training data set composed by M input vectors $x_{1, \ldots,} x_m$, with corresponding target values $y_{1, \ldots,} y_m$ where $y, \in \{-1, 1\}$, new datapoints x can be classified according to the sign of $f(x)$. In the case of linear function f, the model takes the form:

$$f(x) = \omega^t \varphi(x) + b \qquad \text{(Eq. 1)}$$

where $\varphi(x)$ denotes a fixed feature mapping, ω and b are the model parameters. The SVM aims to choose the decision boundary in order to maximize the margin, which is defined to be the smallest distance between the decision boundary and any of the samples. Since the class-conditional distributions may overlap, the exact separation of the data can lead to poor generalization. Thus, the introduction of the slack variables $\varepsilon_i \geq 0$ where i = 1, …, M allows some of the training set data points to be misclassified, and then to overlap class distribution. Then, a SVM problem formulation can be seen as the optimization of the "soft margin" loss function (Cortes and Vapnik 1995).

$$\text{minimize } \frac{1}{2}\, |\omega|^2 + \mathrm{C} \sum_{i=1}^{M} \varepsilon_i \qquad \text{(Eq. 2)}$$

subject to $y_i(\omega^T \varphi(x) + b) \geq 1 - \varepsilon_i$

$\varepsilon_i \geq 0$

The parameter $\mathrm{C} > 0$ is known as box constraint and controls the trade-off between the slack variable penalty and the margin. The procedure for solving Eq. 2 is to construct a Lagrange function from the objective function and the corresponding constraints, by introducing a dual set of variables. The key observation is that the Lagrangian solution leads to the dual representation of the maximum margin problem in which we maximize:

$$\tilde{L}(a) = \sum_{i=1}^{M} a_i - \frac{1}{2} \sum_{i,j=1}^{M} a_i a_j y_i y_j K\left(x_i, x_j\right) \qquad \text{(Eq. 3)}$$

under constraints $\sum_{i=1}^{M} a_i\, y_i = 0$ and $0 \leq a_i \leq C$, where a_i are the Lagrange multipliers and $K(x_i, x_j)$ is the kernel function defined by the Gaussian kernel:

$$K(x_i, x_j) = exp\left(-\gamma \left|x_i - x_j\right|^2\right) \qquad \text{(Eq. 4)}$$

where γ is the kernel scale parameter. The optimization of Eq. 3 takes the form of a quadratic programming problem where the computational complexity in the dual problem (see Eq. 3) depends on the number of samples (i.e., *M*). If $(\hat{a}_i)$ is the solution of the dual problem in Eq. 3, the prediction of new data points can be expressed in terms of the parameters and the kernel function as follows:

$$f(x) = \sum_{i=1}^{M} \hat{a}_i y_i K(x, x_i) + b \qquad \text{(Eq. 5)}$$

Note that any data point for which $\hat{a}_i = 0$ does not contribute to the prediction (see Eq. 5), while the remaining data points constitute the support vectors. SVM hyperparameters (i.e, γ and C) used to solve the machine learning tasks (i.e. classification of grasping movements followed by i. self-actions and ii. other-actions) were chosen in order to minimize the *validation error* within the leave-one-subject-out cross-validation.

Table 3.1

WISC-IV scores for participants of TD group and ASD group

WISC IV scores	TD group		ASD group	
	Mean	SD	Mean	SD
Full scale IQ	102.8	9.4	98.5	11.1
Verbal comprehension	105.3	9.6	98.3	14.6
Perceptual reasoning	107.6	11.4	108.6	11.2
Working memory	102.4	10.8	94.6	10.5
Processing speed	94.4	14.5	89.2	14.9

Table 3.2.

ADOS-2 and ADI-R scores for participants of the ASD group.

	ADOS-2			ADI-R				
Participant	Total Score	SA	RRB	Total Score	A)	B)	C)	D)
1	*8*	7	1	25	*12*	*8*	*3*	*2*
2	*8*	6	2	29	*10*	*10*	*8*	*1*
3	*8*	6	2	30	*12*	*9*	*7*	*2*
4	*8*	6	2	30	*12*	*9*	*7*	*2*
5	*8*	6	2	28	*10*	*11*	*5*	*2*
6	*9*	8	1	25	*10*	*8*	*5*	*2*
7	*8*	6	2	28	*11*	*9*	*4*	*4*
8	*8*	7	1	31	8	17	*5*	*1*
9	*8*	7	1	49	*20*	*15*	*10*	*4*
10	*13*	11	2	21	9	*8*	*3*	*1*
11	*9*	8	1	41	*18*	*19*	*3*	*1*
12	*8*	7	1	30	*11*	*11*	*5*	*3*
13	*8*	7	1	24	*10*	*8*	*5*	*1*
14	*10*	8	2	29	*11*	*8*	*5*	*5*
15	*9*	8	1	32	*12*	*11*	*6*	*3*
16	*8*	7	1	24	*10*	*9*	*4*	*1*
17	*9*	8	1	24	*10*	7	*6*	*2*
18	*8*	7	1	25	*11*	*9*	*3*	*2*
19	*8*	6	2	24	*10*	5	*7*	*2*
20	*7*	6	1	27	*14*	3	*6*	*4*

Note: ADOS-2 (Autism Diagnostic Observation Scale 2) subtests: SA (Social Affect); RRB (Restricted and Repetitive Behaviors). Cut-off score for ADOS-2 Total Score (SA + RRB): (autism = 9; autism spectrum = 7). ADOS-2 Total score range (0–28). ADI-R (Autism Diagnostic Interview-Revised) subtests: A) Qualitative Abnormalities in Reciprocal Social Interaction (cut-off score = 10); B) Qualitative Abnormalities in Communication (cut-off score = 8); C) Restricted, Repetitive, and Stereotyped Patterns of Behavior (cut-off score = 3); D) Abnormality of Development Evident at or Before 36 Months (cut-off score = 1). ADI-R Total score range (0–78). The scores in Italics meet cut-off criteria.

Chapter 4

Table 4.1.

Confusion matrices from LDAs for placing and pouring grasping movements separately for TD and ASD group. Bold values indicate cross-validated grouped cases that were correctly classified. Actual number of observations is shown in parentheses.

Reach-to-grasp performed by TD children			
	Placing	Pouring	*TOT*
Placing	**80.1%** (185)	19.9% (46)	100% (231)
Pouring	17.8% (42)	**82.2%** (194)	100% (236)

Reach-to-grasp performed by ASD children			
	Placing	Pouring	*TOT*
Placing	**68.8%** (154)	31.3% (70)	100% (224)
Pouring	24.9% (57)	**75.1%** (172)	100% (229)

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