# The relationship between pantomime execution and recognition across typically developing and autistic children

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ABSTRACT

*Background:* Motor deficits in autism have a double aspect: on one side, they are neglected by standard diagnostic procedures, on the other they are very frequent (70%) and promising as early indicator of the syndrome. Their characterization is extremely relevant, as they could impact on social abilities based on the understanding of others' actions.
*Method:* Fifty-two typically developing children (TD) and 13 children with autism spectrum disorder (ASD) took part to the study. Children were evaluated in pantomime execution, and in two tasks based on pantomime observation: recognition of pantomime meaning, and error recognition, with observed pantomimes that could contain spatial, temporal or body-part-as-tool errors.
*Results:* TD children performance in tasks based on observation appeared strongly associated to individual motor skills. In general, ASD children exhibited a poorer performance than TD in all tasks. Most interestingly, in both pantomime execution and error recognition they showed a parallel and selective prevalence of spatial errors, whose scores resulted to be correlated with the autistic symptoms severity.
*Conclusions:* In TD children, the capacity to decode the actions done by others relies on the observer motor repertoire. In children with autism, the parallelism between deficits in pantomime execution and recognition suggests that during action observation the motor resonance is impoverished due to an impaired motor repertoire, thus impeding a proper social contact with others.

## 1. Introduction

Ample evidence report the presence of an altered motor development in autism spectrum disorder (ASD). This deficit is described by a large amount of studies (Alaniz et al., 2015; Calhoun, Longworth, & Chester, 2011; De Meyer et al., 1972; Dewey, Cantell, & Crawford, 2007; Dziuk et al., 2007; Dowell, Mahone, & Mostofsky, 2009; Hocking et al., 2014; Jones and Prior 1985; Mostofsky et al., 2006; Jansiewicz et al., 2006; Vilensky, Damasio, & Maurer, 1981), suggesting how motor signs may serve for an early identification of the syndrome. Indeed, although movement impairments are not included in the defining symptomatology of autism, yet they are frequent, with a comorbidity rate around 70% of cases (Lai, Lombardo, & Baron-Cohen, 2014).

Along the same line of research, a large number of prospective studies investigated, in high-risk, delays in the motor development

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with the aim to identify the motor biomarkers potentially associated with later communication and social deficit. Poor gross motor skills, reduced postural control and deficits in fine motor movements have been observed in high-risk (HR) infants since 6 months of age (Bhat, Galloway, & Landa, 2012; Flanagan et al., 2012; Leonard et al., 2014; Libertus & Landa, 2014; Libertus et al., 2014), thus indicating a strong link between motor development and communication abilities. These findings suggested a potential cascading consequence of motor advances on communication development, and proposed the early neurodevelopmental vulnerabilities in HR infants as possible endophenotypes associated with ASD. Therefore, a detailed examination of the early stage motor functions could provide new insights on the relationship among motor performance, social behavior, and symptom severity in ASD (Dowell et al., 2009; Gizzonio et al., 2015; Kaur, Srinivasan, & Bhat, 2018).

Widening to typical development, many studies demonstrated that in infants motor functioning and social behavior are strictly linked, and that the functionality of the first impacts significantly on the latter. EEG studies showed that already at 7–8 months, children present a stronger desynchronization of sensorimotor cortical rhythms in response to the observation of goal-directed actions. This indicates that the ability to analyze others' actions in terms of goal is grounded in the motor system since early childhood, suggesting that it further plays a role in the early development of social understanding (Nyström, 2008; see also Filippi et al., 2016; Marshall, Young, & Meltzoff, 2011). The specificity of this motor resonance relative to one's own motor repertoire was evidenced by van Elk et al. (2008), who reported a stronger EEG mu- and beta- desynchronization in 14- to 16- months-old toddlers when observing a crawling child relative to a walking child. The strength of this effect appeared clearly related to the toddler's crawling experience.

Taken together, these findings demonstrate that in childhood the perception of behavior of others depends also on the development of motor abilities. It is known that the mirror mechanism, i.e. the capacity of the observer to map others' actions onto his own motor system (see for a review Rizzolatti et al., 2014) links these two domains (action and perception) in terms of neural representation since the early days of life (Ferrari et al., 2006). However, scarce are the evidence of a behavioral link between action execution and observation over childhood, as well as of how this link could be modified by the presence of autistic symptoms.

Starting from these assumptions, two are the aims of the present study. On one side, we investigated the relationship between motor performance and action recognition in typically developing children. We expected that children with higher motor skills should perform better also in action recognition and classification. On the other side, we investigated how the motor performance differs in children with autism relative to controls, whether this discrepancy parallels differences in action recognition and, finally, whether these scores may be associated with symptoms severity and alterations in social behavior. The study was carried out on both children with autism and on typically developing (TD) children administering a test essentially based on the Florida Apraxia Battery in its version for children (Mostofsky et al., 2006). Unlike previous studies, we added two observation tasks presenting the same actions performed by an actor. This add-on allowed us to complement the picture about motor performance, social behavior and their possible reciprocal link in both populations.

## 2. Methods

### 2.1. Participants

A total number of 65 children took part to the study. Fifty-two were typically developing children (TD) and 13 were children with a diagnosis of autism or autism spectrum disorder (ASD). The study was approved by the Local Ethical Committee and was conducted according to the Helsinki Declaration. Written informed consent was obtained from parents of each child involved in the study.

The TD group comprised 52 children (30 males and 22 female) between 6 and 11 years of age (mean age: 8.91 ± 1.46 years). They were recruited in a primary school of Parma. They had no reported history of psychiatric treatment, learning disabilities, or neurological disorders.

The ASD sample was composed by 14 children (12 males and 2 female, see Section 3.1.2 for details about the sample size estimation). One of them was subsequently excluded from the sample because of a low compliance to experimental procedures. ASD children ranged from 6 to 11 years of age (mean age: 9.50 ± 1.46 years). They were recruited in two different centers: Pediatric Neuropsychiatry of Unità Sanitaria Locale 11, Empoli and Pediatric Neuropsychiatry of Parma. All ASD children met diagnostic criteria for autism spectrum disorders according to the DSM-5 (APA 2013) and to the ADOS-2 (Autism Diagnostic Observation Schedule, Second Edition, Modules 1–3; Lord et al., 2012). According to their medical records, all children were free from any evident neurological abnormality as well as from hearing or visual impairments.

All participants were administered with two neuropsychological tests: 1) a short version of Leiter International Performance Scale-Revised (Roid, Miller, & Leiter, 2002), a standardized non-verbal test designed to assess cognitive functions in children and adolescents with age between 2 and 20 years and 2) Peabody Picture Vocabulary Test (PPVT), in order to assess the individual receptive (hearing) vocabulary and verbal abilities (Dunn & Dunn, 1981).

A subsample of the TD group (n = 13) was extracted to form a control group against the ASD children. They were selected so as to match the ASD group features in terms of chronological age (mean age: 9.50 ± 1.44 years) and neuropsychological tests.

To distinguish the whole TD group from the matched subsample, from here on we will use the labels TD-all and TD-match, respectively. Table 1 reports the information about all the groups considered in the data analyses.

### 2.2. Experimental procedures

To investigate the link between execution and observation of pantomimes, the experiment was designed as the sequence of two separate sessions, namely "Execution" and "Observation" (see Fig.1), whose scores will be ultimately compared. The presentation

**Table 1**

The characteristics of the evaluated groups, including their age, cognitive and diagnostic evaluations are reported. The first column reports the indices relative to the overall TD population (TD-all, n = 52), while the last column shows those relative to the TD sub-sample (TD-match, n = 13) matched with ASD.

| | TD-all | ASD | TD-match |
|---|---|---|---|
| Sample size | 52 (m: 30) | 13 (m:11) | 13 (m: 9) |
| Chronological age | 8.9 ± 1.46 | 9.5 ± 1.46 | 9.5 ± 1.44 |
| IQ (Leiter-r) | 112.2 ± 14.2 | 90.8 ± 19.1 | 99.5 ± 10.0 |
| PPTV (Peabody) | 109.3 ± 11.7 | 102.2 ± 34.0 | 104.9 ± 13.4 |
| ADOS (social effect) | N.A. | 10.5 ± 4.5 | N.A. |
| ADOS (restricted and repetitive behavior) | N.A. | 1.9 ± 1.3 | N.A. |
| ADOS Total score | N.A. | 12.4 ± 4.3 | N.A. |



**Fig. 1.** Experimental design. Left column refers to pantomime execution. Right column refers to pantomime observation tasks and all examples refer to the pantomime requiring using a glass. In Panel A, the 16 pantomimes performed by children are listed. Panel B, object recognition; Panel C, pantomime recognition task; in Panel D an example of the three choice image is reported; Panel E, error recognition task with the six frames extracted from each glass related video-clip, either correct (top line) or containing different errors (temporal, spatial or BPT); Panel F, the picture used to assist ASD children in the response delivery.

order of the two sessions was kept fixed for all participants, with Execution preceding Observation.

Concerning Execution session, praxis performance was assessed using a part of the Gestures to Verbal Command section of the Florida Apraxia Battery (Rothi et al. 2003), modified by Mostofsky et al. (2006). It included 16 pantomimes, which required the child to show how to hold and use a tool (Fig. 1, Panel A). Examples include "Show me how you would hold scissors and cut a piece of paper in front of you" or "Show me how to use a glass to drink water". The participants were free to choose the hand for performing pantomimes.

During the test, participants were frontally videotaped in order to capture the global movement. Subsequently, an independent scorer rated the children performance during each trial following the guidelines provided in Mostofsky et al. (2006). Each gesture was scored evaluating the presence of five different types of errors: 1) No response/Unrecognizable error (*Nr/Ur*) was assigned when the participant either did not respond to a command or if the pantomime was not identifiable; 2) Body Part for Tool errors (*BPT*) are referred to the use of a part of the body (i.e. finger, hand, arm) as the tool during the execution of a pantomime; 3) Content/Concretization errors (*Conc*) indicate that the content of the pantomime is incorrect. This type of error is labeled as a *Content* error

when a pantomime is correctly performed, but is different from the requested one, and as a *Concretization* error when the subject acts on a real object rather than on an imagined object; 4) Temporal errors (*Temp*) are typically attributed to pantomimes whose timing, sequence, and/or occurrence is performed incorrectly; and finally 5) Spatial errors (*Spat*) include any movement alterations in terms of reduction or magnification of the amplitude of the pantomime, and/or failure in the spatial relationship between the arm/hand and the objects involved in the trial. Each responded and recognizable trial could, in principle, show more than one type of error.

The Observation session was subdivided in three different tasks: object recognition (Fig. 1, Panel B), pantomime recognition (Fig. 1, Panel C), and error recognition (Fig. 1, Panel E). In the object recognition task, 16 pictures depicting the objects previously imagined during pantomime execution (e.g. hammer, glass, scissors, etc.) were presented to the child, who had to name them. This task was introduced in order to ensure that participants were familiar with all the objects implied by the subsequently presented pantomimes.

In the pantomime recognition task, participants were required to identify the same 16 pantomimes previously executed, but now performed by an actor (Fig. 1, Panel C). In order to verify whether the observed pantomime had evoked an implicit representation of the action without an access to verbal explanation, a panel containing three objects was subsequently presented (Fig. 1, Panel D). Of them, one was the object actually represented by the pantomime just seen, while the others were unrelated. The child had to indicate which object was pantomime-related, so to evaluate whether the vision of the pantomime-related object could trigger the explicit response in trials initially failed.

The error recognition task (Fig. 1, Panel E) was created on the basis of the results obtained in a previous study (Gizzonio et al., 2015). Forty pantomimes - performed by an actor - could either be executed in a correct way, or contain one of the three most common errors (i.e. spatial, temporal and BPT errors) according to Gizzonio et al. (2015). First, the object implied by the upcoming pantomime was shown to the child (e.g. glass). Afterwards, children observed the pantomime (either correct or not) and had not to recognize its meaning, but rather to label it as correctly performed or not. In the latter case, they had also to indicate which kind of error they had noticed. Thus, children had to pay attention not on "what" the actor was performing, but on "how" the actor performed it. This specific task was grounded on the notion that different neural circuits subserve the perception of *what* and *how* an action is executed (de Lange et al., 2008; Thioux, Gazzola, & Keysers, 2008) and that these circuits can be specifically impaired in clinical populations (Rochat et al., 2013). To assist ASD children in the response delivery without interfering with the task accomplishment, the experimenter used an image with 6 panels illustrating all the possible outcomes (Correct, Spatial: too large or too small movements, Temporal: too fast or too slow, Body Part as Tool). On this panel, ASD children could point to the chosen selection (Fig. 1, Panel F).

## 2.3. Statistical analysis

The statistical analysis was subdivided in two parts: the first was aimed at depicting the performance in a TD population, while the second analysis compared the performance of 13 children with autism with a subsample of 13 children, taken from the main TD sample, and matched one-by-one with ASD for age, cognitive level (IQ) and receptive verbal ability (PPVT).

In a preliminary correlational analysis, all scores obtained in the experimental sessions were tested, for each group, against IQ and PPVT scores with the aim to evaluate the possible impact of both cognitive level and verbal abilities on the children performance. Significance threshold was set at 5% after Bonferroni correction. Furthermore, the correlation with Age was also evaluated to define which parameters were age-dependent.

### 2.3.1. TD group

*Execution session:* The percentage of trials presenting errors, regardless their type constitutes a general quality index of praxis (named *overall performance*). Higher values indicate worse performances. The percentage of trials presenting each specific error type was evaluated, and a rmANOVA was conducted with ErrorType (5 levels: Nr/Ur, BPT, Conc, Temp, and Spat) as within subjects factor to render which errors mostly contributed to children performance. Post-hoc analysis was conducted with Bonferroni correction.

*Observation session:* Concerning object recognition task, no statistical analysis was conducted, as this task was just intended as an internal control on the knowledge about the objects involved in the task. If an object was not recognized, the trials referring to it were discarded and not accounted in all the subsequent analyses.

In the pantomime recognition task, the percentage of pantomimes not correctly recognized was calculated. The same computation was also applied for the responses obtained after the presentation of the panel with three objects. The incremental accuracy between the second and the first response was named as 'advantage' and its significance was tested via a one-sample *t*-test against the chance level (33%).

Finally, the scores obtained in the error recognition task were submitted to a rmANOVA with ErrorType as factor (4 levels: Correct, Spat, Temp, and BPT), so to identify whether errors were equally recognized, and if not so, which errors were least recognized. Bonferroni correction was applied.

The correlation between all the scores in observation tasks and the overall performance in execution was tested in order to reveal possible dependencies between cognitive functions and motor abilities. Bonferroni correction was used to account for multiple comparisons. If significant, such results would provide evidence that the level of motor development underpins perceptual capabilities. Of note, the preliminary correlation analysis defined the set of variables affected by age, IQ and verbal abilities. To ensure that significant correlations between execution and observation were not due to age-dependency, we further applied a partial correlation model on the relations-of-interest, where values were adjusted for age (i.e. a not-of-interest effect).

### 2.3.2. TD vs ASD

In order to compare TD and ASD children, 13 participants were selected from the whole TD sample, as the ones best matching with children with autism in terms of chronological age and cognitive and verbal abilities. A t-test was conducted on Age, IQ and PPVT across the two groups, which showed no difference for the three investigated variables. We carried out two rmANOVA, one for scores in execution and one for scores in observation, aimed at comparing the performances between the matched subsample and the whole TD group (n = 52). In both cases, we used Group (TD-match and TD-all) and Index (all scores of each session) as factors. To ensure that the selected subsample is representative of the entire TD population, we checked for the absence of any main effect of Group as well as of any interaction Group*Index.

*Execution session:* A rmANOVA with Group (ASD and TD-match) as between subjects, and Error Type (Nr/Ur, Conc, Spat, Temp, BPT) as within subjects factors, was performed with the aim to compare the motor performance between TD and ASD. A planned comparison design was used for post-hoc analysis, where each Error-Type was tested between groups. Bonferroni correction (N = 5) was used to account for multiple comparison. The same analysis was repeated comparing ASD and TD-ALL groups.

*Observation session:* The performance in pantomime recognition was studied with a one-way ANOVA including Group (ASD and TD-match) as between-subjects factor. A one-sample t-test was conducted for the advantage against the chance level (33%), separately for the two groups. A second rmANOVA was conducted on scores in error recognition, considering Group (ASD and TD-match) as between-subjects, and Error Type (None, Spat, Temp, and BPT) as within-subjects factors. Bonferroni correction (N = 4) was used to account for multiple comparison.

Beyond the accuracy in error recognition task, also the frequency of each stimulus-response combination for the different stimulus types (correct, and with spatial, temporal or BPT errors) is a variable of interest, as it may reveal biases in labeling pantomime errors for one of the two populations. For this reason, we computed these values, separately for TD-ALL, ASD and TD-match.

Finally, all execution and observation scores of ASD children were tested in a linear correlation analysis (Pearson) against the severity of their symptoms as returned by ADOS test. In particular, three scores were considered as regressors: Social Affect (AS), Repetitive behaviors (RRB) and comparative ADOS total score.

## 3. Results

A preliminary correlation analysis concerning *neuropsychological indices* revealed that neither IQ nor verbal abilities exert a significant effect on the performance of TD-all and ASD groups in both execution and observation sessions. Similarly, no significant correlation was found between execution scores and age. In contrast, the correlation analysis on *Age* pointed out a significant and negative correlation with the error rate obtained in pantomime recognition task, for both group (TD-all: $r(50)$ = -0.50, p = 0.005 Bonferroni-corrected; ASD: $r(11)$ = -0.78, p = 0.007 Bonferroni-corrected).

### 3.1. TD group

*Execution session:* The average percentage of errors obtained during pantomime execution resulted to be 38% ($SD$ = 14%). The rmANOVA, carried out to assess which error types were mostly present, indicated a significant ErrorType effect ($F(4, 204)$ = 49.57, p < 0.001). Post hoc analysis (Bonferroni corrected, all p < 0.001) revealed that spatial errors were the most frequently encountered (21%); NR/UR and Conc were rarely present (1% and 4%, respectively), while temporal and BPT errors lied in between (11% and 9%) (see Fig. 2, Panel A).

*Observation session:* Children did not show any difficulty in the preliminary test on object recognition (average error rate at about 3%). They also performed rather well in the pantomime recognition task (see Fig. 3, Panel B), with an average error rate of 12% ($SD$ = 8%) and individuals values ranging from 0 to 38%. Responses following the vision of the panel with three objects improved the performance (average error rate 5%, range 0–25%). The advantage provided by the explicit 3 choice images significantly exceeded the chance level (33%, p < 0.001).
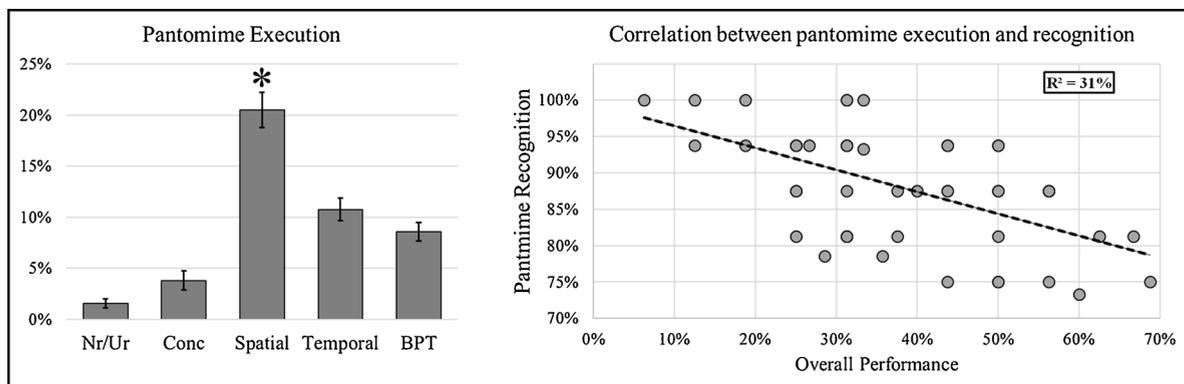


**Fig. 2.** Pantomime execution and its correlation with pantomime recognition. Panel A: Frequency of each error type in pantomime execution for the TD group. Asterisk indicates the error type significantly differing from all other error types at post-hoc analysis. B: Grey dots represent pantomime recognition scores against performance in pantomime execution. The black dashed line represents the linear trend best-fitting the data distribution.
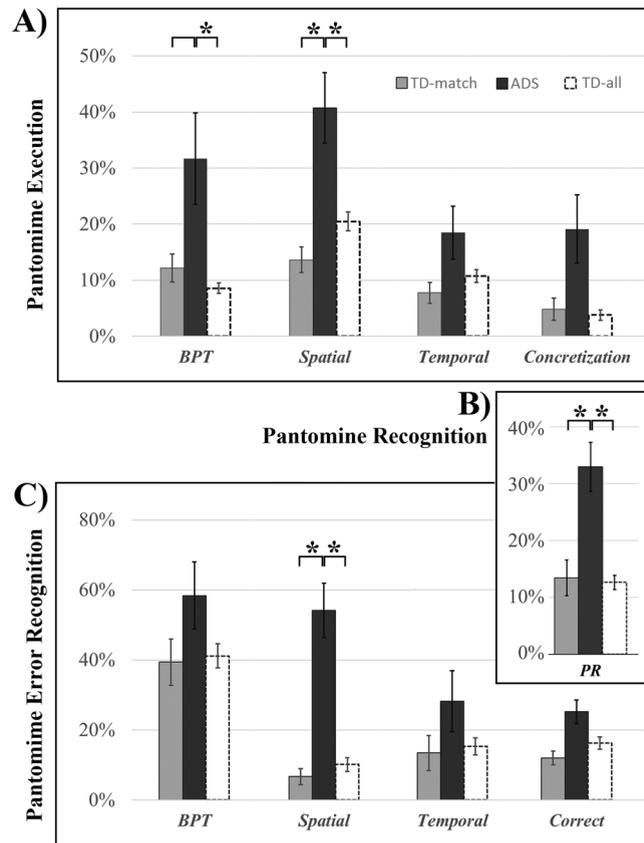
**Fig. 3.** Error types in pantomime execution and pantomime error recognition for ASD and TD children.
Series for ASD children (dark grey) and for the matched subsample of children (TD-match, light grey) are reported. For completeness, also data for the overall TD group (TD-all, white bars) are shown. Panel A: Errors during pantomime execution. Bars indicate standard error. Asterisks indicate scores significantly differing between groups at post-hoc analysis (p < 0.05, Bonferroni-corrected). Panel B: Error rate observed in pantomime recognition. Panel C: Scores in pantomime error recognition

The results of the error recognition task are shown in Fig. 3, Panel C (white columns). The rmANOVA returned a significant main effect of ErrorType ($F(3, 153) = 34.09$, $p < 0.001$). Post-hoc analysis revealed that BPT errors were the most frequent (39.7%) relative to Spat (11%), Temp (15.8%) and correct (16.3%) pantomimes, all $p < 0.001$.

Table 2 shows the frequency of each stimulus-response combination for the different stimulus types. Note that the large majority of misclassified trials are pantomimes containing an unnoticed error, i.e. labeled as correct. In other words, all pantomimes containing errors, if not correctly classified, were labeled as correct.

*Correlation between execution and observation:* Once assessed the performance of children in execution and observation conditions, we performed a correlation analysis aimed at revealing how the performance in execution could relate to the scores obtained in pantomime observation (Fig. 2, Panel B). Results highlighted a significant correlation between the overall performance in pantomime execution and pantomime recognition ($r(50) = 0.369$, $p = 0.035$ Bonferroni corrected). A similar relationship was highlighted also with the degree of recognition of correct pantomimes ($r(50) = 0.367$, $p = 0.035$ Bonferroni corrected). To rule out that these results were a by-product of age-dependencies, we validated them through a partial correlation model adjusting for the effect of age, which further confirmed the significant relationships ($r(50) = 0.33$, $p = 0.020$, $r(50) = 0.32$, $p = 0.018$, respectively). Such results tie together the motor skills of children with both the capacity to recognize the action implied by a pantomime, on one side, and the ability to identify its correct performance by others, on the other side.

### 3.2. TD vs ASD

On the basis of the results relative to the whole TD group, we estimated the sample size of an ASD children group in order to have the possibility to demonstrate an effect similar to that reported in Gizzonio et al. (2015). In that study, authors reported that ASD made twice more errors than TD children. Using the mean and standard deviation in overall performance for TD children, we thus computed the sample size necessary to demonstrate an overall performance score double with respect to the TD group, and the same procedure was applied to the scores in pantomime recognition. In these computations, the enrollment ratio was set to 1 with the aim to subsequently match subject per subject the two groups, alpha was set to 1% and power to 90%. The requested sample size resulted

**Table 2**

For each investigated population, the average number of each stimulus-response combination is reported (upper part of each cell) along with the percentage (lower part) over the total number of trials of each type (16 for correct, 8 for spatial, temporal and BPT errors). Cells along the diagonal indicates accuracy for each stimulus type, and are colored in grey.

| Pantomime Error | Participant Response | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TD-all | | | | ASD | | | | TD-match | | | |
| | Correct | Spatial | Temporal | BPT | Correct | Spatial | Temporal | BPT | Correct | Spatial | Temporal | BPT |
| **Correct** | 13,39 | 0,68 | 1,55 | 0,38 | 11,97 | 1,34 | 2,22 | 0,47 | 14,30 | 0,35 | 0,93 | 0,42 |
| | 83,70% | 4,22% | 9,67% | 2,40% | 74,79% | 8,38% | 13,90% | 2,93% | 89,36% | 2,19% | 5,84% | 2,61% |
| **Spatial** | 0,69 | 7,16 | 0,15 | 0,00 | 1,55 | 3,41 | 2,70 | 0,34 | 0,76 | 7,14 | 0,10 | 0,00 |
| | 8,62% | 89,50% | 1,88% | 0,00% | 19,43% | 42,58% | 33,70% | 4,29% | 9,50% | 89,29% | 1,22% | 0,00% |
| **Temporal** | 1,24 | 0,06 | 6,70 | 0,00 | 1,44 | 0,82 | 5,74 | 0,00 | 1,31 | 0,00 | 6,69 | 0,00 |
| | 15,56% | 0,75% | 83,69% | 0,00% | 17,99% | 10,22% | 71,79% | 0,00% | 16,33% | 0,00% | 83,67% | 0,00% |
| **BPT** | 2,99 | 0,17 | 0,12 | 4,73 | 2,44 | 0,97 | 0,95 | 3,64 | 3,28 | 0,10 | 0,17 | 4,46 |
| | 37,35% | 2,09% | 1,49% | 59,07% | 30,49% | 12,11% | 11,94% | 45,47% | 40,94% | 1,19% | 2,11% | 55,76% |

to be 4 for overall performance, and 14 for pantomime recognition, so we selected 14 as the numerosity for ASD group.

The comparison between ASD and TD children in terms of neuropsychological indexes and age indicated no significant differences between the two groups in terms of IQ ($t(11) = 1.49$, $p = 0.16$), PPVT ($t(11) = 0.27$, $p = 0.79$), and Age ($t(11) = 0.04$, $p = 0.96$). To further examine for group differences in IQ, PPVT and Age, we used a Bayesian analysis, with two priors. The Scaled JZS Bayes Factor (IQ: 1.24, PPVT: 2.76 and Age: 2.76) and Scaled-Information Bayes Factor (IQ: 0.9, PPVT: 2.06 and Age: 2.06) both failed to provide evidence of group differences for all the three variables (Rouder et al., 2009). The two rmANOVA comparing the whole TD group with its subsample in all execution and observation scores did not return any significant effect involving the Group factor.

*Execution session:* The rmANOVA on the performance during the execution returned a significant main effect of Group ($F(1, 24) = 20.11$, $p < 0.001$) and ErrorType ($F(4, 96) = 10.73$, $p < 0.001$), as well as a significant Group*ErrorType interaction ($F(4, 96) = 2.49$, $p = 0.047$). As shown in Fig. 3 (Panel A), post hoc analysis, carried out via a planned comparison design testing each error type between the two groups, indicated spatial errors as the only ones discriminating ASD (41%) from TD (14%, $p = 0.006$ Bonferroni-corrected, Cohen's $d = 1.58$). A tendency towards significance characterized BPT errors (TD: 12%, ASD: 32% $p = 0.07$, $d = 0.9$). This effect was indeed strengthened when considering the whole TD population ($p < 0.001$).

*Observation session:* Comparing the performance of the two groups during pantomime recognition, the one-way ANOVA returned significant main effects for Group ($F(124) = 13.33$, $p = 0.001$), with ASD exhibiting the highest number of errors (TD: 14%, ASD: 33%) (Fig. 3, Panel B). Responses following the vision of the panel with three objects images presented lower error rates (TD: 6%; ASD: 16%). The advantage provided by the explicit 3 choice image resulted to be equivalent between groups, with values 45.8% and 56.3%, respectively, both significantly exceeding the chance level (33%; all $p < 0.001$).

The rmANOVA with Group (ASD and TD) as between-subject factor and Error Type (Correct, Spat, Temp, and Bpt) as within-subject factor returned a significant main effect for both Group ($F(1, 24) = 14.27$, $p < 0.001$) and Error Type ($F(3, 72) = 12.03$; $p < 0.001$), with ASD making a higher number of errors than TD, and BPT the error type least recognized in both groups. The interaction Group*ErrorType ($F(3, 72) = 4.68$, $p = 0.005$) resulted to be significant. Post-hoc analysis (see Fig. 3, Panel C) revealed that only *spatial errors* significantly differentiated the performance of the two groups, with ASD making this error type almost six times more than TD group (TD: 10.71%; ASD: 57.97%; $p < 0.001$ Bonferroni-corrected).

To strengthen how the TD-match sub-sample was representative of the whole TD group, we repeated the same analyses comparing ASD with TD-ALL. These results were fully confirmed, as visible in Fig. 3.

When evaluating stimulus-response combination for ASD and TD-match groups, highly difference patterns emerge. Similarly to TD-all, TD-match tended to over attribute correctness to pantomimes containing errors, but no cross-talk appeared between error types. On the contrary, this cross talk became evident for ASD group, with in particular spatial errors labeled as temporal one out of three times.

### 3.3. Correlation analysis between the severity of ASD symptoms and the performance scores

Finally, the correlation analysis between the performance scores obtained in both execution and observation conditions by ASD children and the severity of their symptoms evaluated by ADOS test was performed. A significant correlation was found between the

**Table 3**

Correlations results between performance and symptoms' severity in ASD children. The first column reports results relative to ADOS total score (comparative score), while the last two columns refers to the two ADOS subscales (Social Affect and Repetitive Behaviors). Each cell reports the Pearson coefficient and the relative p-value. The highlighted cells indicate a significant correlation.

| | | ADOS total score | Social Affect | Repetitive Behaviors |
|---|---|---|---|---|
| **Pantomime Execution** | Total Error | R: 0.441 p= 0.151 | R: 0.406 p= 0.190 | R: 0.096 p= 0.765 |
| | NR/UR | R: -0.268 p= 0.399 | R: -0.090 p= 0.780 | R: -0.035 p= 0.914 |
| | Conc | R: -0.114 p= 0.723 | R: -0.063 p= 0.845 | R: -0.063 p= 0.846 |
| | Spatial | R: 0.751 p= 0.005 | R: 0.679 p= 0.015 | R: 0.012 p= 0.969 |
| | Temporal | R: 0.219 p= 0.493 | R: 0.337 p= 0.283 | R: 0.358 p= 0.253 |
| | BPT | R: -0.255 p= 0.424 | R: -0.336 p= 0.285 | R: 0.112 p= 0.727 |
| **Pantomime Recognition** | | R: 0.028 p= 0.931 | R: -0.184 p= 0.565 | R: 0.620 p= 0.131 |
| **Error Recognition** | Correct | R: -0.499 p= 0.098 | R: -0.624 p= 0.030 | R: 0.203 p= 0.526 |
| | Spatial | R: 0.542 p= 0.068 | R: 0.565 p= 0.055 | R: -0.060 p= 0.852 |
| | Temporal | R: 0.219 p= 0.494 | R: 0.242 p= 0.449 | R: 0.428 p= 0.164 |
| | BPT | R: 0.236 p= 0.459 | R: 0.042 p= 0.896 | R: 0.573 p= 0.051 |

ADOS comparative score and 1) the spatial errors during the execution on one side, and 2) the degree of recognition of spatial errors during error recognition task on the other. Of note, moving to the correlation against SA and RRB subscores, only the first maintained the same pattern, while it was not present at all for the latter. All correlation results are shown in Table 3.

## 4. Discussion

In the present study, we assessed the motor performance of TD children and children with ASD in executing pantomimes, established their capacity to understand the meaning and correctness of pantomimes executed by others and, most importantly, tested the existence of mutual relationships between these two domains.

Concerning TD children, the main result of the experiment was the presence of a significant correlation between the performance in pantomime execution with two aspects of pantomime observation, i.e. the score obtained in pantomime recognition task and the degree of recognition of correctly performed pantomime in the error recognition task. This means that, on one side the motor performance of TD children sustains their ability to recognize the pantomime meaning, on the other it favors the capacity to identify whether a pantomime is correctly executed by others. As such, children with poorer motor skills in pantomime execution exhibit a lower capacity to recognize the same pantomimes performed by others. At the same time, they are more prone to fail in error recognition, mostly labeling as correct pantomime executed wrongly. Of note, by using a partial correlation analysis, we ruled out that this link is age-dependent. These data support the notion of a close link between one's own motor repertoire and the capacity to decode the "what" and the "how" of an action executed by others. Overall, this finding reinforces the importance of an early development of motor abilities in children, in order to boost the capacity to understand the behavior of others. To our knowledge,

such a result constitutes the first behavioral demonstration that the process of action recognition, in children, impinges on their motor skills.

The neural substrate most likely underlying these findings is represented by the parieto-frontal action-execution/action-observation circuit, also named mirror network. This circuit maps the sensory representation of the observed motor behavior onto the observers' motor areas allowing the observer to directly understand others' actions, i.e., without inferential processing (Rizzolatti et al., 2014). The fact that pantomime recognition grounds on individual motor performance is in line with previous studies demonstrating that the motor system is recruited according to how the observed action belongs to the observer own motor repertoire (Calvo-Merino et al., 2005; Cross, Hamilton, & Grafton, 2006). Notably, this resonance is not modulated by the visual familiarity, but rather by the degree of direct motor experience in both adults (Calvo-Merino et al., 2006) and toddlers (van Elk et al., 2008).

BPT errors deserve a specific point. Indeed, although TD children recognized correctly virtually all pantomimes, they often failed in recognizing BPT errors. The mismatch between the BPT-free execution and the poor recognition of BPT errors in observation may be due to their focusing on the semantic aspect of the observed pantomime, and to a lesser extent on the details of how the pantomime was executed. Another interpretation of this results could be that children indeed perceive the use of a body part as a tool by the actor, however, being this symbolically consistent with the pantomime meaning, they do not label it as an error.

Concerning ASD children, results indicated a generally poorer performance in both pantomime execution (see Mostofsky et al., 2006) and recognition with respect to TD group. In particular, a prevalence of spatial errors was evident during pantomime execution. These data are in line with previous findings by Gizzonio et al. (2015), in which spatial errors dominated with respect to other error types in both experimental conditions requiring pantomime execution (i.e. verbal command and imitation). The hypothesis that authors supported is that children with autism, during development, build a peculiar internal motor model. This model emerges every time a given action is executed, and becomes particularly evident during imitation task. In this case, ASD children do not replicate the gestures exactly as shown by the experimenter, but rather they imitate the action goal using their own stereotyped style. The observed kinematic is imitated only when ASD children are explicitly requested to do so (see also Hobson & Lee, 1999; Hobson & Hobson, 2007). The peculiarity of a motor style during execution is in line with what reported also by several physicians and therapists, who describe the difficulty of "adjusting the size of the action" in terms of magnitude by ASD children (see also Chu et al., 2014).

The other aspect of the motor development investigated by our study concerns the capacity to recognize errors purposely inserted into the observed pantomimes. Compared to TD children, ASD group presented a poorer capacity in recognizing spatial errors. Taken together with data from execution task, spatial errors emerge as the primary contributor to the poorer ASD performance. This conclusion is in line with previous literature showing that children with autism have difficulty in understanding both spatial relationships (Churchill, 1972, 1978) and spatial orientation (up–down, front–back, left–right, Wing, 1969).

To further reinforce the link between autism and spatial errors, a convincing argument comes from the correlation analysis in which spatial errors appeared to be positively correlated with ADOS score, both in execution and recognition tasks. These results are in line with previous data by Cook, Blakemore, and Press (2013), who reported a triple connection among motor performance, action recognition and ADOS scores an ASD adult population. In this study, individuals with autism performed movements with atypical kinematics, and the degree to which kinematic was atypical correlated with a bias towards perceiving biological motion as 'unnatural' and with the severity of autism symptoms as measured by the ADOS.

The parallelism between the impairments in pantomime execution and recognition suggests that in autism a motor disorganization is mirrored onto how one perceives the actions made by others. Because mirror mechanism appears to be involved in many aspects of social interaction, several authors suggested that dysfunctions of this mechanism could explain some of the primary social symptoms of autism, including isolation and absence of empathy (see Dapretto et al., 2006; Iacoboni & Dapretto, 2006; Oberman & Ramachandran, 2007; Williams et al., 2001). However, the results of the present study are more in line with a later hypothesis advanced by Cattaneo et al. (2007), who proposed that typical deficits of ASD are not to be found in a primary deficit of the mirror mechanism, but rather as consequence of an extensive disorganization of the motor system. This disorganization, in turn, would impact on the capability to map the observed actions onto the one's own motor system. As such, the cause is not to be found in a problem of the echoing mechanism, but rather in the detuning between self and other.

Taken together, this evidence indicated that in ASD population the deficits of action execution and those of action observation are strongly related. Most importantly, their extent is tied to the severity of autistic symptoms suggesting that motor deficits do constitute one of the key elements of autistic symptomatology.

### 4.1. Limitations and future research

To our knowledge, this is the first study to combine behaviorally action execution and action observation in typically developing children and children with autism. However, some limitations need to be pointed out. While the number of enrolled TD children is quite large, the number of recruited ASD children is relatively low. Despite it is in line with the sample size analysis reported in Methods section, this also depends on the difficulty encountered in recruiting children capable to accomplish the whole battery of tasks, requiring a minimum level of attentive, cognitive and verbal abilities.

Future research should aim at collecting larger samples, possibly administering a whole battery of tests about motor functions and integrating data with kinematic measurements during execution to provide quantitative and not only qualitative indicators about the movement organization in children with autism. Similarly, during observation tasks an improvement could derive from adopting strategies to overcome the necessity of an explicit response, thus allowing researcher to include and test also ASD children with poor

verbal and cognitive abilities. These advancements would provide a more global picture of the relationship between motor and cognitive domains in ASD.

### 4.2. Clinical implications

Beside its neurophysiological relevance, this study supports the importance of neurorehabilitive and abilitative programs pointing to an early enrichment of the individual motor abilities in pediatric age. In addition to its physical and motor value, this would provide children with competences that are crucial during social interaction.

Concerning motor organization in ASD, the main challenge remains the identification of the motor-signatures atypically developed in children with autism. In this vein, here we pointed that the spatial organization of the action, as well as the poor sensitivity to spatial anomalies in the actions performed by others, could be considered as a red flag along pre-diagnostic clinical pathways. These motor patterns, whose onset often precedes the development of verbal and communicative abilities, could be tested as biomarkers in high-risk population, possibly predicting the later development of the syndrome.

### Conflict of interest

The authors have no conflict of interest to report.

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