Neurotypical individuals fail to understand action vitality form in children with autism spectrum disorder

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Any defects of sociality in individuals diagnosed with autism spectrum disorder (ASD) are standardly explained in terms of those individuals' putative impairments in a variety of cognitive functions. Recently, however, the need for a bidirectional approach to social interaction has been emphasized. Such an approach highlights differences in basic ways of acting between ASD and neurotypical individuals which would prevent them from understanding each other. Here we pursue this approach by focusing on basic action features reflecting the agent's mood and affective states. These are action features Stern named "vitality forms," and which are widely assumed to substantiate core social interactions [D. N. Stern, *The Interpersonal World of the Infant* (1985); D. N. Stern, *Forms of Vitality Exploring Dynamic Experience in Psychology, Arts, Psychotherapy, and Development* (2010)]. Previously we demonstrated that, although ASD and typically developing (TD) children alike differentiate vitality forms when performing actions, ASD children express them in a way that is motorically dissimilar to TD children. To assess whether this motor dissimilarity may have consequences for vitality form recognition, we asked neurotypical participants to identify the vitality form of different types of action performed by ASD or TD children. We found that participants exhibited remarkable inaccuracy in identifying ASD children's vitality forms. Interestingly, their performance did not benefit from information feedback. This indicates that how people act matters for understanding others and for being understood by them. Because vitality forms pervade every aspect of daily life, our findings promise to open the way to a deeper comprehension of the bidirectional difficulties for both ASD and neurotypical individuals in interacting with one another.

vitality form | autism | motor cognition

Autism spectrum disorder (ASD) is a neurodevelopmental condition with heterogeneous clinical manifestations, including deficit in social skills, verbal and nonverbal communication, and restricted and repetitive behaviors (1). Longstanding lines of research have attributed the lack of sociality in individuals diagnosed with ASD to their putative impairments in a variety of cognitive functions. For instance, individuals with ASD have been shown to exhibit reduced ability and developmental delay in mind reading (2–4; see also, 5). Similarly, there is evidence that individuals with ASD perform poorly in recognizing others' emotional expressions (6–9) as well as in evaluating their feelings (10; see also, 11, 12).

No doubt, understanding how others think and feel helps us promote social interaction. However, this may be not the whole story. Indeed, effective social interactions may depend not only on understanding others, but also on making others understand us. Recent studies in the ASD domain suggest the need for a bidirectional approach to social interaction (12, 13). This approach highlights differences in basic ways of acting between ASD and neurotypical individuals which could hamper their

making themselves understood by others. Accordingly, difficulty in social interaction for ASD individuals could result from the failings of both ASD and neurotypical actors to understand each ptother. Indeed, ASD emotional expressions have been shown to be difficult for neurotypical individuals to recognize (14–18), and this difficulty can provoke in them a negative initial feeling when facing people with ASD (19). Similarly, peculiar movements and reactions in a social context have been shown to prevent neurotypical perceivers from inferring ASD individuals' beliefs and desires (20, 21), with critical implications for social dynamics (22).

Here we explore neurotypical individuals' ability to deal with ASD action by focusing on basic motor features which may reflect the mood and the affective state of an agent. These are motor features Stern named "vitality affects" (23) and, later, "vitality forms" (24) to distinguish them from emotional reactions. To illustrate, consider an everyday action such as passing a glass of wine to a friend. You might pass it gently, or it might happen that you do it rudely. Even minimal variations in the unfolding of your action can be enough to make it look like rude rather than gentle, thus enabling your friend to recognize your mood.

Significance

Action vitality forms are highly pervasive aspects of daily life and have been widely assumed to be critical for basic social interactions. Previous evidence indicates that ASD children express their own vitality forms in a way that is motorically dissimilar to TD children. Here we demonstrate that this motor dissimilarity prevents neurotypical adults from recognizing vitality forms, when observing ASD children acting gently or rudely. Although ASD children differentiate these vitality forms, neurotypical adults were remarkably inaccurate in identifying them. This indicates that difficulty in social interaction for ASD individuals should not be entirely ascribed to their lack of understanding others, as standardly assumed. The failure of neurotypical individuals to understand them plays a critical role too.

In a previous study we recorded the kinematics of ASD children and typically developing (TD) children when performing different types of action (e.g., placing, throwing, and passing) characterized by different vitality forms (e.g., gentle and rude). Like TD children, ASD children executed gentle and rude actions differently, as indicated by kinematic parameters such as peak velocity and peak acceleration. These parameters varied similarly in both groups. However, unlike TD children, ASD children did not differentiate the vitality forms to be expressed by systematically modulating a spatiotemporal parameter such as movement time (25). Does this difference in vitality form expression between ASD and TD children have any impact on neurotypical individuals' ability to understand ASD styles of acting?

This question is particularly pressing, for two reasons at least. The first reason is that vitality forms are pervasive in every aspect of our daily life, and their expression and recognition have been widely assumed to be critical for social bonding in children as well as in adults (26–28). Vitality forms therefore offer an opportunity not only to probe a core dimension of social interaction, but also to account for its potential dysfunctioning (29). The second reason is that there is evidence that ASD children and adolescents have difficulty in both recognizing (30, 31) and imitating (32, 33) vitality forms when expressed by neurotypical actors. Investigating whether neurotypical observers recognize vitality forms expressed by ASD actors may provide deeper insight into the bidirectional difficulty both ASD and neurotypical individuals face in interacting with each other.

To investigate how differences in vitality form expression may have consequences for vitality form recognition, we carried out a study in which neurotypical participants were presented with two videos showing two different types of actions (placing vs. throwing) performed with two different vitality forms (rude vs. gentle). Notably, but unknown to participants, half the actions were executed by ASD children and the other half by TD children. The videos were obtained by extracting kinematic signals from our previous study (25) and consisted of point-light stimuli (PLS) depicting six markers located in the upper limb and connected to each other by red segments. Fig. 1 exhibits an example of the presented stimuli, that is, a placing-a-bottle action executed either gently (Fig. 1, Top) or rudely (Fig. 1, Bottom) by a TD child (for some illustrative videos, see also Movie S1).

In the first experiment (experiment 1), participants were instructed to pay attention to how the action was executed (gently or rudely) and to judge—as fast and accurately as possible—whether the vitality form of the second video was the same as that of the first one, regardless of the type of the presented actions (Vitality Form [VF] task). In the same experiment, participants were also requested to pay attention to which action was executed (placing or throwing) and to judge—as fast and accurately as possible—whether the type of action of the first video was the same as the one of the second video, regardless of the vitality form of the observed actions (Action Type [AT] task).

While experiment 1 was directed to assess neurotypical individuals' possible difficulty in understanding vitality forms when expressed by ASD children, a further experiment was carried out to inquire into the reasons for this possible difficulty (experiment 2). Differently from experiment 1, participants were presented with an information feedback about the correctness of their answers. Information feedback has been shown to often result in an improvement in the ability to discriminate unusual visual features, making observers more sensitive to similarities or differences that may happen to be initially hard to be detected (34–36). By contrasting participants' performance when observing vitality forms with and without information feedback, we sought to scrutinize whether possible difficulty in identifying similarities or differences between vitality forms expressed by ASD children was primarily due to the visual features of the presented stimuli. If this were the case, one should expect a perceptual learning effect in the vitality form recognition task performed with information feedback. Conversely, the lack of a perceptual learning effect would suggest that reasons other than the visual unusualness might hamper neurotypical observers in recognizing vitality forms when expressed by ASD individuals.

Results

Experiment 1. A repeated-measure two-way ANOVA was performed on the sensitivity index (d'), with Task (two levels, VF and AT) and Actors Group (two levels, ASD and TD) as within-factors. The two-way ANOVA showed a main effect of Task ($F_{(1,19)} = 106.53$, $P < 0.001$) and a main effect of Actors Group ($F_{(1,19)} = 57.95$, $P < 0.001$). As illustrated by Fig. 2A, participants were more accurate in the AT task than in the VF task and when observing TD actions than when observing those performed by ASD children. Interestingly, there was a significant interaction between Task × Actors Group ($F_{(1,19)} = 7.71$, $P = 0.012$), with participants' accuracy being much lower in the VF task when observing ASD actions than when observing TD actions (mean $d' \pm$ SD are reported for the VF task: ASD = 1.23 ± 0.47, TD = 2.17 ± 0.94; AT task: ASD = 3.07 ± 0.70, TD = 3.37 ± 0.33).

-Furthermore, we measured participants' reaction times (RTs) in the VF task. The Wilcoxon test performed on RTs between ASD and TD actors' trials showed a significant difference ($Z = -3.92$, $P < 0.001$), revealing that participants took longer time to judge those vitality forms expressed by ASD children than those expressed by TD children (Fig. 2B).

Finally, to rule out the possibility that participants' performance in vitality form recognition could have been merely driven by considering how fast or slow the observed actions were, instead of evaluating their rudeness or gentleness, we carried out a control experiment in which an independent group of participants were presented with the same stimuli as in the VF task, but were asked to judge about their velocities rather than their vitality forms (Velocity task). Two independent sample t tests on d' between the VF task and the Velocity task, both within ASD actors' trials and within TD actors' trials, were computed. The results
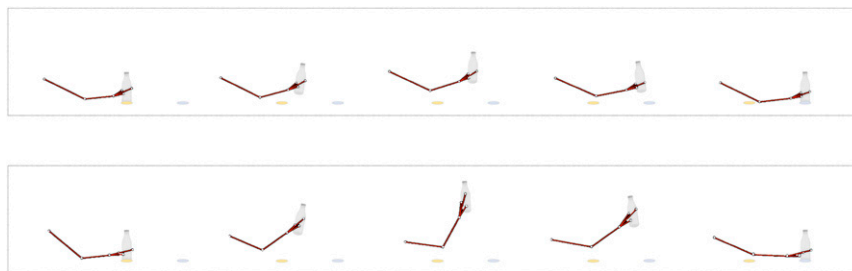
Fig. 1. The figure depicts an example of the presented stimuli, notably the placing action executed gently (*Top*) and rudely (*Bottom*). Stimuli refer to one of the TD actors. Note that the bottle was not included in the videos. Participants were visually presented with the action kinematics only.
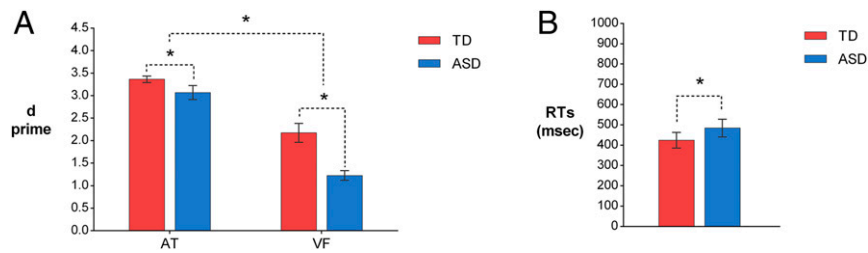
Casartelli et al.

Fig. 2. Graphs illustrating results of experiment 1 on the sensitivity index (d') (*A*) and RTs (*B*). Legend: * = statistical significance, $P < 0.05$. Bars represent standard errors of the mean (SEM).

showed significant differences both within ASD actors' trials ($t_{(38)} = 6.52$, $P < 0.001$; mean $d' \pm$ SD for the VF task = 1.24 ± 0.48 and for Velocity task = 0.30 ± 0.43) and within TD actors' trials ($t_{(38)} = 2.12$, $P = 0.04$; mean $d' \pm$ SD for the VF task = 2.24 ± 0.83 and for Velocity task = 1.72 ± 0.73) (*SI Appendix*, Fig. S1*A*). Two Mann–Whitney *U* tests carried out on RTs between the VF task and the Velocity task showed no significant differences neither within ASD actors' trials nor within TD actors' trials (all $P > 0.36$) (*SI Appendix*, Fig. S1*B*). Taken together, these results indicate that participants did not perform the VF task by simply assuming that "rude corresponds to fast" and "gentle corresponds to slow." This is also in line with Stern's view (23), according to which the notion of vitality form could not be reduced to a single kinematic parameter, even if relevant, such as velocity.

Experiment 2. The stimuli were the same as in experiment 1. A repeated-measure two-way ANOVA was performed on d', with Actors Group (two levels, ASD and TD) and Learning (six levels, corresponding to the six blocks) as within-factors. The two-way ANOVA showed a main effect of Actors Group ($F_{(1,17)} = 71.76$, $P < 0.001$; mean $d' \pm$ SD for ASD = 1.58 ± 0.50 and for TD = 2.08 ± 0.52). This confirms the results of experiment 1, in which participants were more accurate when judging vitality forms expressed by TD than by ASD actors. No significant effect of Learning or Actors Group × Learning was found (all $P > 0.10$).

To compare participants' performance in the VF task in experiment 1 (without feedback) and experiment 2 (with feedback), another repeated-measure two-way ANOVA was conducted on d', with Actors Group (two levels, ASD and TD) and Learning (five levels, corresponding to the five blocks) as within-factors and Task (two levels: VF without feedback and VF with feedback) as between-factor. A significant main effect of Actors Group ($F_{(1,34)} = 99.36$, $P < 0.001$) was found, whereas no significant main effects of Learning ($P > 0.05$) or Task ($P > 0.43$) were found, nor any interactions ($P > 0.16$) (Fig. 3*A*).

Furthermore, a repeated-measure two-way ANOVA was conducted on reaction times, with Actors Group (two levels,

ASD and TD) and Learning (six levels, corresponding to six blocks) as within-factors. A significant main effect of Actors Group ($F_{(1,17)} = 21.51$, $P < 0.001$) was found, in line with the results of the VF task in experiment 1. In addition, we found a significant effect of Learning ($F_{(5,13)} = 9.76$, $P < 0.001$), indicating a decrease in RTs through blocks. No interaction effect Actors Group × Learning was found ($P > 0.13$) (Fig. 3*B*).

Finally, a repeated-measure two-way ANOVA was conducted on confidence rate with Actors Group (two levels, ASD and TD) and Learning (six levels, corresponding to the six blocks) as within-factors. No significant main effect of Actors Group ($P > 0.06$), Learning ($P > 0.07$) or interaction effect of Actors Group × Learning ($P > 0.25$) were found (Fig. 3*C*).

Discussion

The aim of the present study was to assess whether and to what extent neurotypical adults understand ASD children performing different actions with different vitality forms. There were two main findings. The first finding was that participants were much slower and less accurate in recognizing vitality forms when expressed by ASD children than when expressed by TD children (experiment 1, Fig. 2 *A* and *B*). Note that participants' performance was not driven by taking rude as just synonymous for fast as well as gentle for slow, as our control experiment demonstrated (*SI Appendix*). The second finding was that information feedback did not help participants in recognizing ASD vitality forms. Indeed, their performance was still poor, without any significant improvement (experiment 2, Fig. 3*A*).

The first finding seems to be in line with two very recent studies investigating neurotypical individuals' ability to read ASD minds. In the first study, Sheppard et al. (21) asked neurotypical participants to infer what had happened to other people from some videos recording their reactions to different greeting scenarios. Half of the targeted people were diagnosed with ASD and half were without ASD. The results showed that participants were generally more accurate in inferring the greeting scenario when viewing neurotypical people than when viewing people with ASD (see also 22).
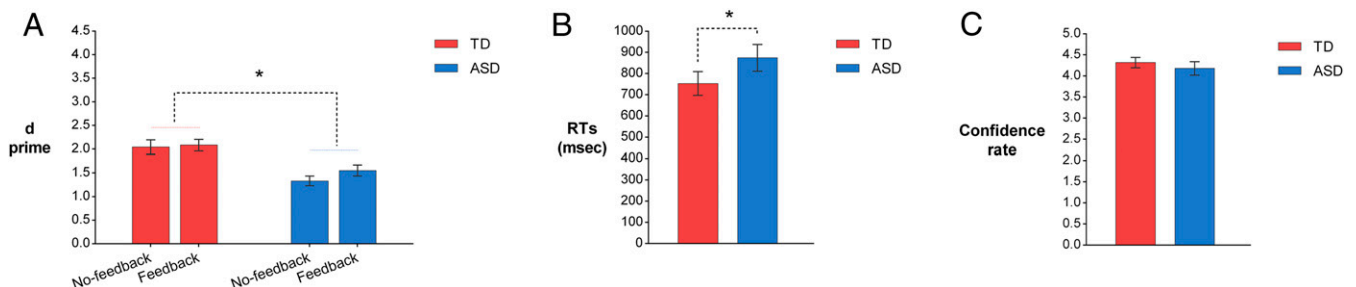

Fig. 3. Graphs illustrating the results of experiment 2 on the sensitivity index (d') (*A*), RTs (*B*), and confidence rate (*C*). Legend: * = statistical significance, $P < 0.05$. No-feedback = VF task, experiment 1. Feedback = VF task, experiment 2. Bars represent standard errors of the mean (SEM).

Casartelli et al.

In the second study, Edey et al. (20) took advantage of an adapted version of a Heider–Simmel task (37, 38) in order to assess neurotypical adults' ability in inferring the mental states of people with ASD. Neurotypical participants and participants with ASD were presented with animations consisting of two triangles which enacted mental states like coaxing, mocking, seducing, and surprising. The animations had been previously generated by the participants themselves, who held in their hands triangular magnets and moved them on a table top. Interestingly, neurotypical participants had more difficulty in attributing the intended mental states to the animations produced by participants with ASD than to those produced by neurotypical participants. The authors ascribed this difficulty to the atypical kinematics exhibited by participants with ASD in generating the animations. Indeed, the animations generated by the movements of participants with ASD were found to exhibit more jerks than their neurotypical counterparts.

What our finding shows is that neurotypical adults difficulty in understanding individuals with ASD extends to much more basic and pervasive social skills than those described by Sheppard et al. (21) and Edey et al. (20). Our task did not require inferring relatively complex mental states from the observation of either greeting scenarios or abstract animations. Rather, participants had to judge whether or not two very familiar actions, such as placing a bottle and throwing a ball, had the same vitality form (whether they were both gentle or both rude).

Vitality forms are critically involved in expressing and recognizing our own mood and affective states (24). Most of our actions are characterized by specific vitality forms, and the ability to identify these forms takes a fundamental role in successfully interacting with others (26–28). The fact that participants were highly inaccurate in recognizing ASD vitality forms indicated that neurotypical individuals' difficulty in understanding ASD is deeper than previously thought, as it is rooted in a core social skill.

It is worth noting that vitality forms should not be confused with emotions. Vitality forms are related to action features which lack vegetative and motor components typical of emotional responses. There is evidence that neurotypical individuals are highly accurate in identifying emotion when observing facial expression produced by other neurotypical individuals, while their performance is much poorer when they have to recognize the facial expression of ASD individuals (16–18). Our finding extends this evidence to the vitality form domain, taking a step toward a better understanding of how many basic features of autistic behavior may be hard for neurotypical individuals to read.

But can neurotypical observers' difficulty to identify vitality forms when expressed by ASD children be explained? As already mentioned, the video-clips presenting ASD and TD actions were extracted from a database obtained in a previous study (25). In this study we recorded the kinematics of ASD and TD children while performing placing and throwing actions with two different vitality forms (i.e., gentle and rude). Several kinematic parameters (e.g., peak velocity, peak acceleration) indicated that, like TD children, ASD children executed gentle and rude actions differently. However, unlike TD children, ASD children did not take advantage of a specific parameter such as movement time in order to express the different vitality forms. Indeed, while TD children systematically varied their movement time to differentiate gentle from rude actions, with the latter being basically shorter in time than the former, ASD children tended to take approximately the same time when executing gentle and rude actions, with rude being even longer than gentle actions in around 30% of cases. So, although ASD children were able to understand the concepts of rudeness and gentleness, and following the instructions did try to implement the corresponding vitality forms, they did not appear to express them motorically in a way similar to TD children.

It is tempting to link the difficulty of the neurotypical participants in understanding ASD vitality forms to the peculiar

kinematics displayed by ASD in expressing them. Neurotypical adults have been shown to recognize the vitality forms of other neurotypical adults by making use of brain processes and representations similar to those involved in vitality form expression (39). This has led to the hypothesis that observing someone else acting with a given vitality form would involve a transformation of the sensory information concerning the observed action into processes and representations which would occur if the observers were expressing that vitality form themselves. If the observed actions match the internal representation of corresponding vitality forms, this would allow the observers to recognize them as well as to track the related mood or affective states (40).

This hypothesis could explain why ASD children have been demonstrated to be impaired in recognizing (30) and imitating (32, 33) vitality forms when expressed by neurotypical adults. More interestingly, it could also explain the first finding of the present study, that is, why neurotypical adults turned out to have prominent difficulty in understanding vitality forms when expressed by ASD children. When observing ASD children acting in the VF task, participants could not have matched the sensory representation of the observed action kinematics onto their own processes and representations of corresponding vitality form.

One might wonder whether participants' difficulty in recognizing vitality forms expressed by ASD children was mostly related to a general opacity of autistic bodily movements. It is true that clinicians usually refer to generic motor atypicalities in ASD individuals. This is also certified by several studies in the literature (41–46) as well as by the introduction in the DSM-5 of motor functioning atypicalities as an associated feature of ASD (even if—notably—they are not diagnostic criteria for ASD; see 1). We are far from denying that these atypicalities could have somehow impacted participants' performance in recognizing ASD vitality forms. However, it is likely that neurotypical difficulty in recognizing ASD vitality form might also depend on motor deficit in ASD individuals specifically concerning the modulation of vitality form expression. This is in line with our previous study which demonstrated that ASD and TD children's kinematics selectively differed in the vitality form expression despite being similar with respect to the action type components (25). A similar dissociation between vitality form and action type has also been found in ASD children when asked to imitate various actions characterized by specific vitality forms (32, 33).

The hypothesis that neurotypical adults' difficulty in understanding vitality form expressed by ASD children could be primarily due to their inability to match ASD children's action kinematics onto a corresponding internal model seems to account for our second finding too. Indeed, experiment 2 showed that providing feedback on the correctness of their answers did not significantly improve participants' performance in recognizing ASD vitality forms. It is known that information feedback may enhance visual sensitivity in perceptual discrimination tasks (34–36). In principle, participants could have taken advantage of some visual cues (e.g., arm trajectories) differentiating vitality forms one from another. However, their performance in ASD vitality form recognition remained rather low, even after receiving information feedback. This suggests that mere visual features were not sufficient for capturing the observed vitality forms. Our proposal is that participants were hampered in accurately understanding the ASD vitality forms because of a mismatch with their own way of expressing motorically the corresponding vitality forms.

There is a large body of evidence showing that a match (or a mismatch) of action kinematics is likely to have critical implications for the understanding of others. On the one side, atypical kinematics in movement execution has been shown to be linked in ASD individuals to difficulty not only in categorizing biological movements (44), but also in identifying the motor intention

underlying the observed action (47–52). On the other side, neurotypical individuals have been shown to be better in predicting the outcome of observed actions when these actions are kinematically similar to their own (53–56). Furthermore, skilled individuals outperform novices when asked to recognize observed actions, with motor expertise impacting on action understanding even in absence of a corresponding visual expertise (57, 58). Finally, several studies point to a critical role for motor skill acquisition in the development of action understanding (for a review, see 59).

It is worth noting that our proposal that neurotypical observers had difficulty in understanding ASD vitality form because of a specific mismatch with their own way of expressing motorically the corresponding vitality form does not imply that ASD individuals would not have such difficulty when observing another ASD individual performing an action with a given vitality form. Quite the contrary. We did not test here ASD individuals' ability to identify vitality forms when expressed by ASD actors. However, it is absolutely compatible with our proposal that ASD observers could exhibit the same kind of difficulty in identifying vitality forms expressed by ASD actors as they demonstrated when the vitality forms to be recognized were expressed by neurotypical actors (30). We previously demonstrated that, in contrast to neurotypical actors, ASD actors tend to express their own vitality forms without any systematic variation of a characterizing feature such as their movement time (25). Note that Stern himself pointed out that movement time variation is critical for vitality form expression and recognition (24). The lack of this characterizing feature could make vitality form expression by ASD individuals less motorically informative not only for neurotypical but also for ASD observers. They could therefore both have more difficulty in identifying the so expressed vitality form.

This is also in line with previous studies demonstrating that ASD individuals lack any "group" advantage in dealing with other ASD individuals. For instance, there is evidence that ASD observers are largely inaccurate in recognizing emotional expressions not only in neurotypical but also in ASD actors (17; see also, 12). Similar results have been obtained by Edey et al. (20). Their study showed that while neurotypical participants demonstrated an enhanced ability to attribute the intended mental state to the animations produced by other neurotypical participants, relative to those produced by ASD participants, ASD participants are similarly inaccurate in assigning the intended mental state to animations produced by both ASD and neurotypical individuals.

How people act matters for understanding others as well as for being understood by others. Our key point is that this primarily holds in the vitality form domain. Indeed, the difference between TD children's and ASD children's kinematics in vitality form expression was reflected in neurotypical adults' difficulty in understanding ASD children's vitality forms. Given that vitality form expression and recognition substantiate almost every social interaction, our findings promise to open the way to a deeper comprehension of the bidirectional difficulty both ASD and neurotypical individuals face in attempting to understand each other. And this may have critical implications for successful interaction between educational professionals and ASD children (29, 60).

Methods

Experiment 1.

Participants. Twenty adult participants (mean age ± SD = 25.60 ± 4.38 y, all males) were recruited. All participants had normal or corrected-to-normal vision and reported no history of neurological or psychiatric disorders. All participants were university students or had at least one previous university degree. Left-handed individuals, as indicated by a questionnaire adapted from the Edinburgh Handedness Inventory (61) for Italian native speakers, were excluded. All participants provided informed consent approved by the local Ethics Committee (Scientific Institute, IRCCS Eugenio Medea). The entire study protocol was approved by the Scientific Institute for Rehabilitation

Medicine, IRCCS Eugenio Medea Ethics Committee and conformed to the principles elucidated in the Declaration of Helsinki.

Stimuli. In a previous study from our group (25), we recorded TD and ASD children kinematics when performing different types of actions with different vitality forms by using an optoelectronic motion capture system (OEP system, BTS Bioengineering). Here, we benefited from the outputs of the motion capture system to create ad hoc and well-controlled video-clips in which PLS depicting a six-markers set were connected to each other by red segments. The six-markers set was applied to the right upper limb, and more precisely to the arm acromion, the elbow (lateral epicondyle), the wrist (radial styloid process), the third metacarpal head, the fingernails of the index, and of the thumb.

In the present experiment, we selected two types of action (placing a bottle and throwing a ball), and stimuli were extracted from six participants (three children with ASD, three TD children; all males; hereafter, "actors"). The two distinct types of action were performed alternatively with two different vitality forms (gentle and rude, respectively). Among the more reliable PLS stimuli that we extracted from each actor (i.e., stimuli with lower kinematic data loss), we selected one trial for each combination (i.e., placing–gentle; placing–rude; throwing–gentle; throwing–rude). To sum up, we combined two types of action (placing/throwing), two vitality forms (gentle/rude), and two actors groups (three ASD actors, three TD actors). We ended up with 24 single videos.

There was an obvious small variability among the time duration of the videos (mean duration ± SD = 1.60 ± 0.60 s). To minimize potential perceptual confounds, we controlled the global time duration of each video adding a short time of a black screen and few still frames at the beginning (mean duration ± SD = 2.50 ± 0.50 s) and at the end (0.20 s). With this procedure we obtained videos which substantially reached the same total time duration (mean duration ± SD = 3.90 ± 0.10 s). The 24 videos were pseudorandomly coupled in order to obtain 48 stimuli. Each couple of videos differed for either the type of action (placing a bottle vs. throwing a ball) or the vitality form (gentle vs. rude). More specifically, 24 stimuli showed the same type of action performed with different vitality form (e.g., placing a bottle gently and placing a bottle rudely), whereas the other 24 ones showed two different types of action performed with the same vitality (e.g., placing a bottle gently and throwing a ball gently). Noteworthy for our aims, videos were coupled within the two actors groups: 50% of the videos depicted ASD children's actions, while the other 50% of the video presented TD children's actions. Finally, we added six stimuli as catch trials showing the same type of action and the same vitality form (e.g., moving a bottle gently + moving a bottle gently), and they were randomly presented during the experiment.

Eight different stimuli and three catch trials were created to be used in the brief practice session performed by each participant before starting the task.

Procedure. Participants were sitting in a dimly lit room in front of a laptop screen (HP 250 G3, Notebook PC-15). The stimuli were presented using E-prime 2. Each trial started with a fixation cross at the center of the screen (1-s duration), then after 0.25 s the stimulus was presented. After the stimulus presentation (i.e., a couple of videos), the response window was showed (max duration 3 s). Before the start of the next trial, an intertrial interval of 2 s was set. An example of a single trial is exemplified in *SI Appendix*, Fig. S2.

In the experimental session, participants were asked to perform seven separate blocks, each of them containing the same 54 trials randomly presented (48 experimental stimuli + 6 catch stimuli). Our primary aim was to test participants' vitality form recognition ability (VF task), whereas the discrimination of different types of actions served as internal control condition (AT task). For this reason, we set five blocks for the VF task and two blocks for the AT task. We could therefore reduce the length of experimental sessions, maximizing the number of trials for our condition of interest (i.e., VF task).

Participants were requested to respond by pressing the keyboard buttons corresponding to "Yes" or "No" answer (the buttons were randomized to be balanced across participants). In the VF task, participants were instructed to pay attention to how the action was executed (gently or rudely) and to judge—as fast as possible—whether the vitality form of the first video was the same compared to the vitality form of the second one, regardless of the type of the presented actions (placing a bottle or throwing a ball). Symmetrically, in the AT task, participants were requested to pay attention to the type of action (placing a bottle or throwing a ball) of the first video and to judge—as fast as possible—whether the type of action of the first video was the same compared to the type of action of the second one, regardless of the vitality form (gentle or rude) of the actions. The order of the two tasks (VF task, AT task) was randomized to be balanced across participants. Before

Casartelli et al.

each task, participants performed a brief practice session to gain confidence with the task. The videos used in the practice were different compared to the ones employed in the experimental session (see *Methods, Experiment 1, Stimuli*). The experimental session globally lasted around 2 h.

Statistical data analysis.

Sensitivity index (d prime). We computed the sensitivity index (d') (62) as a measure of accuracy:

$$d' = Z(Hit\ rate) - Z(False\ Alarm\ rate)$$

Concerning the VF task, hits were defined as trials in which the two videos showed the same VF (rude or gentle), and participants correctly judged them as "the same vitality form" ($\rightarrow$ "Yes" answer). In the AT task, hits were defined as trials in which the two videos showed the same type of action (placing a bottle or throwing a ball), and participants correctly judged them as "the same type of action" ($\rightarrow$ "Yes" answer). Accordingly, false alarms in the VF task were defined as trials in which the two videos showed different vitality forms, and participants wrongly judged them as showing the same vitality form. False alarms in the AT task were defined as trials in which the two videos showed different types of action, and participants wrongly judged them as showing the same type of action.

A repeated-measure two-way ANOVA was performed on d', with Task (two levels, VF and AT) and Actors Group (two levels, ASD and TD) as within-factors. Participants performed two blocks of the AT task. In order to have the same number of observations in both tasks, the VF task d' was computed on two blocks. For each participant we randomly selected two out of five blocks of the VF task (each block, from the first to the fifth, was equally selected).

Reaction Times. We computed RTs in the VF task only. The specific features of AT task prevented the reliable evaluation of RTs. First of all, RTs may be more impacted than other measures (e.g., d') by the limited number of blocks ($n = 2$). Most importantly, we opted for a randomization of tasks being essential to control potential order effects. This implies that for half of the participants the AT task was at the beginning of the experiment (first and second blocks), whereas for the others it was at the end of the experiment (sixth and seventh blocks). RTs were filtered at single participant level in order to exclude responses longer and shorter than 2 SD from the participants' mean RTs. Mean was computed for ASD and TD actors' trials separately. We used a Wilcoxon test to explore the impact of ASD actors' vs. TD actors' trials on participants' RTs.

Experiment 2.

Participants. An independent sample of 18 TD adult participants was recruited (mean age $\pm$ SD = 24.89 $\pm$ 6.04 y; all males). Participants were matched for chronological age with the participants of experiment 1 ($t_{(36)} = 0.42$, $P = 0.68$). All participants had normal or corrected-to-normal vision and reported no history of neurological or psychiatric disorders. All but one participant were university students or had at least one previous high school/university degree. Left-handed individuals, as indicated by a questionnaire adapted from the Edinburgh Handedness Inventory (61) for Italian native speakers, were excluded. All participants provided informed consent approved by the local Ethics Committee (Scientific Institute, IRCCS Eugenio Medea). The entire experimental practice conformed to the principles elucidated in the Declaration of Helsinki.

Stimuli. The stimuli were the same as in experiment 1.

Procedure. The experimental procedure was similar to the VF task (experiment 1), given that participants were requested to judge—as fast and as accurately as possible—whether the vitality form of the first video was the same compared to vitality form of the second one, regardless of the type of action (i.e., placing a bottle or throwing a ball). However, the procedure provided two main differences compared to the VF task in experiment 1. First, participants received feedback about the accuracy of their answer (a green tick or a red cross mark was presented on the screen for correct and incorrect answers, respectively). Second, after their answer and before the feedback, participants were also requested to evaluate their confidence with a Likert scale (from 1 to 5, from "low confidence" to "high confidence"), with no time constraints. Feedback about accuracy and confidence rate were inserted to explore the potential learning effect across blocks.

Differently from experiment 1, here we set six blocks in order to explore the possible learning effect in vitality form recognition. In addition, we removed the time constraint in the response window to avoid any pressure to participants. This was done following pilot testing in which we observed that participants generally need more time to answer, probably because of the double answer required. All of the remaining parts of the procedure were identical to the VF task (experiment 1). The experimental session globally lasted around 2 h.

Statistical data analysis.

Sensitivity index (d prime). We computed the sensitivity index (d') at a single-block level for each participant. This procedure allowed us to test the potential effect of learning during the experiment. In the VF task performed with feedback, a repeated-measure two-way ANOVA was conducted on d', with Actors Group (two levels, ASD and TD) and Learning (six levels, corresponding to the six blocks) as within-factors. In a further analysis, we compared the VF task performed without (experiment 1) and with feedback (experiment 2). In order to have the same number of observations in both tasks, we computed the d' at a single-block level for each participant also for the VF task without feedback (experiment 1). A repeated-measure two-way ANOVA was performed on d', with Actors Group (two levels, ASD and TD) and Learning (five levels, corresponding to the five blocks) as within-factors and Task (two levels: VF without and with feedback) as between-factor.

Reactions times. A repeated-measure two-way ANOVA was conducted on RTs, with Actors Group (two levels, ASD and TD) and Learning (six levels, corresponding to six blocks) as within-factors.

Confidence rate. A repeated-measure two-way ANOVA was performed on confidence rate with Actors Group (two levels, ASD and TD) and Learning (six levels, corresponding to the six blocks) as within-factors.

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