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A mind-reading puzzle: Autistic people are more efficient at a theory-of-mind task

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ABSTRACT

Theory of Mind (ToM) is essential to adapt in social situations; however, a ToM deficit might be involved in autism. To better understand how ToM reasoning affects problem solving in autistic and non-autistic individuals, we compared autistic and non-autistic children and adults in a series of problems presented in social and non-social framings, using an adapted version of a classical referential communication task. In the social framing, participants were asked to anticipate the behavior of an agent who might ignore some components of the scene. In the non-social framing, the task required participants to consider and ignore similar features of the scene, but an agent was not involved. Simply framing the task as a social one increased the difficulty, particularly for non-autistic participants. Interestingly, the framing had less of an impact on autistic participants, who showed better performance in the social task relative to non-autistics and maintained similar performance across framings. We propose that autistic participants might have translated the social instructions into a general rule that proved more efficient in this situation. Our findings suggest a critical distinction between ToM understanding and the continuous use of a ToM strategy in repeated situations.

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1. Introduction

Autism spectrum disorder (ASD)[1] is a neurodevelopmental disorder characterized by impairments in communication and social interaction, as well as restricted, stereotyped behavior and interests (American Psychiatric Association, 2013). The clinical phenotype is broad, encompassing a large range of behaviors and intellectual abilities, resulting in a highly heterogeneous population. A lower drive for social interaction (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012), atypical perception of social stimuli (Yang, Rosenblau, Keifer, & Pelphrey, 2015) as well as an atypical pattern of executive functions (see Wilson et al., 2014 for a review) and/or perception (Mottron, Dawson, Soulieres, Hubert, & Burack, 2006) have all been associated with ASD. Regarding cognitive functioning, poor "Theory of Mind" has been associated with autism (see Baron-Cohen, Tager-Flusberg, & Cohen, 2000 for a review).

Theory of Mind (ToM) classically refers to the ability to mentally represent others' behaviors in terms of mental states such as thoughts (e.g., beliefs, representations) and will (e.g., desires, goals) (Baron-Cohen, Tager-Flusberg, & Cohen, 2000). To efficiently predict behavior based on ToM, one must take the perspective of others and consider what they know or ignore and the information they have access to. One limiting aspect of ToM reasoning is sometimes inhibiting one's own knowledge. As a whole, ToM plays an important role in social interactions. Importantly, it allows us to navigate our personal and social world by explaining past behavior, understanding actions, and anticipating them (Frye & Moore, 2014). Most ToM skills develop gradually between 2 and 6 years, but some studies show that ToM continues to develop into adolescence (Bamicha & Drigas, 2022; pp. 7, 1200; Carlson, Koenig, & Harms, 2013; pp. 7, 1200; Keysar, Lin, & Barr, 2003; pp. 7, 1200; Scheeren, de Rosnay, Koot, & Begeer, 2013; pp. 7, 1200; Symeonidou, Dumontheil, Chow, & Breheny, 2016; pp. 7, 1200).

Over the past decades, many studies have shown a limited ToM ability in autistic individuals, which could explain certain characteristics of their social behavior (Baron-Cohen, 1989; Baron-Cohen, Leslie, & Frith, 1985; Frith & Happé, 1995; Frith, 1989; Hobson, 1993; Leslie & Frith, 1988). Subsequent meta-analyses comparing theory of mind abilities of autistic individuals to controls have also confirmed this proposition (Baron-Cohen, Tager-Flusberg, & Cohen, 2000; Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998). When examining performance on various tasks assessing the understanding of mental states, autistic individuals have demonstrated an impairment in their use of ToM.

To assess ToM, tasks that require referential communication have been widely used in previous research (Keysar, Lin, & Bar, 2003; Resches & Pereira, 2007; Begeer, Malle, Nieuwland, & Keysar, 2010; Dumontheil, Apperly, & Blakemore, 2010; Scheeren et al., 2013). Referential communication occurs when a speaker, during a conversation, refers to specific things, persons, or events in order to convey information. Successful referential communication depends crucially upon metarepresentational skills such as awareness of the listener's perspective (Roberts & Patterson, 1983). Thus, referential communication is also a mentalizing ability. Indeed, studies have shown that participants with a higher ToM level performed better at referential communication tasks (Dahlgren & Sandberg, 2008; Maridaki-Kassotaki & Antonopoulou, 2011; Resches & Pereira, 2007).

Among the referential communication tasks that have been developed in previous years is the Director's task, designed by Keysar, Barr, Balin, and Brauner (2000). In this task, adult participants are placed in front of a 4 × 4 grid that contains various objects, and they are instructed by a director (who is also the experimenter) to select certain objects. However, certain slots in the grid are hidden from the director only, meaning that the location of some objects are mutually visible to both the participant and the director, whereas other objects are visible only to the participant but not the director. For example, when the director tells the participant to move "the tape," the intended target must be the mutually visible tape. However, if the participant fails to take the director's perspective, he or she may consider the occluded tape as the referent. This confusion may delay the identification of the actual target tape and possibly cause the participant to mistakenly move the occluded tape that the director could not have referred to, which would be considered an egocentric error. This task requires the spontaneous and repeated use of ToM to interpret the other person's behavior within an unfolding social interaction. To master the critical trials of the task, participants must consider the perspective of the director and select the object that can be seen by both individuals. Participants may select the wrong object, thus making an egocentric error, when choosing an object that is not mutually visible as a potential referent. In this case, the object can only be seen from their perspective (Keysar et al., 2000). This task is well known for assessing one's ability to represent what another person can see (i.e. perspective taking), a core component of ToM, and it has been broadly used as such in previous studies (Apperly et al., 2010; Dumontheil et al., 2010; Keysar et al., 2003).

Performance on the Director's task has led to various interpretations over the years, but the conclusions that have been drawn have not always been consistent across studies. Non-autistic participants have sometimes shown poor performance on the Director's task, which supported the idea that the use of ToM in social interactions could be limited even for typically developing adult participants (Apperly et al., 2010; Keysar et al., 2003). However, other researchers have made different interpretations based on similar results (Rubio-Fernández, 2017; Symeonidou et al., 2016; Lin, Keysar, & Epley, 2010). Rather than interpreting poor performance on the task as a failure to use ToM in interactions, they understood it as a possible effect of other cognitive processes, such as executive control or attention. For example, inhibition could be involved when the participant chooses not to select the corresponding object if it is not seen

[1] Terminology: There is no consensus on how to refer to people with autism. Preferences are set by groups or organizations 1. Kenny L, Hattersley C, Molins B, Buckley C, Povey C, Pellicano E. Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism* 2016; **20**(4): 442–462. The different formulations can emphasize the individual (person), an aspect of his identity (autism) or the pathological nature of his condition (disorder). In this article, the expression "autistic individuals" will be used most often. In reference to the specific diagnosis, the terms "autism" and "autism spectrum disorder" (ASD) will be used 2. American Psychiatric Association. *Diagnostic and statistical manual of mental disorders (DSM-5®), Fifth Edition*. American Psychiatric Publishing: Arlington, VA, 2013, 991pp.

by the director. This alternate explanation brings us to question whether results of autistic individuals' performance on the Director's task clearly indicate that they display an impaired ToM, as previous literature suggests. Indeed, a difficulty in disentangling ToM processes from cognitive demands has also been previously reported (Apperly, 2012). Nevertheless, there is a paucity of research examining this question using a referential communication task such as the Director's task. The few studies that have compared the performance of autistic and control participants (adolescents and adults) on the Director's task (Begeer et al., 2010; Santiesteban, 2015) did not find any difference between the groups, a result that led to multiple interpretations once again. Some researchers suggested that autistic individuals might not have a systematically deficient ToM after all (Begeer et al., 2010), but it was also proposed that they might not use ToM to solve the task (Santiesteban, 2015). In this regard, it is known that there is a strong interaction between ToM and executive function (Pellicano, 2010; Pellicano, Maybery, Durkin, & Maley, 2006), and one possible explanation was the use of other cognitive abilities to solve classic ToM tasks. Overall, no consensus has been reached among the scientific community as to whether performance on a referential communication task, such as the Director's task, shows that the autistic population has a ToM deficit. Thus, further research is needed to gain a better understanding of the capacity and limits of the ToM of autistic individuals, and the influence of general cognitive demands on ToM functioning in the context of social interactions.

In our study, we adapted the Director's task to include a social and a non-social framing to test the impact of a social framing on egocentric errors. By adding a non-social framing, we aimed to control for general executive demands of the task and contrast performance between framings. The goal of the current study was to investigate the use of ToM reasoning and to compare the performance of autistic children and adults with the performance of typically developing controls. Consistently with the vast literature suggesting a ToM deficit in the autistic population, we hypothesized that autistic individuals would perform less well than control participants in the social framing of the task, which relies on ToM reasoning.

2. Method

2.1. Participants

Participants' demographic characteristics are summarized in Table 1. Participants of all ages were recruited as part of a larger ongoing investigation for a Genetics Study (Principal investigators: Prof Leboyer and Prof Bourgeron). Since age distribution was clearly bimodal, participants enrolled in the study were included in two distinct age groups, children (N = 25) and adults (N = 46), forming a total of 33 individuals with ASD and 38 IQ and age-matched controls. In the ASD group, there were 27 males and 6 females whereas in the control group, there were 20 males and 18 females. The recruitment strategy was the same for both groups. We decided to include children and adults in our study because our research question concerns autism at large and we wanted to optimize the power of our analysis. In this regard, we conducted a power analysis with G*Power 3.1.9.7 ($\alpha = 0.95$ and power= 0.80). We chose a medium effect size (Cohen's f=0.25) based on effect sizes of previous meta-analysis on theory-of-mind in autism that reported an average medium effect size (Wang, Chen, Zou, & Qiu, 2020; White & Castelli, 2019). The power analysis shows us that the required total sample size must be at least 24 to obtain an adequate power.

Intelligence quotients (IQ) were determined by the Wechsler Intelligence Scales appropriate for each age. Participants with ASD met criteria for ASD on the Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2000) and/or the Autism Diagnostic Interview-Revised (Lord, Rutter, & Le Couteur, 1994), and had to fulfill the DSM-IV-TR criteria for autism, Asperger's syndrome or PDD-nos. Final diagnosis was based on the consensus of psychiatrists and psychologists specialized in ASD research and clinical work. No significant differences in age and IQ were found between autistic individuals and controls in either children or adult groups, or in the overall group. Participants in the ASD group were recruited from two outpatient clinics of university hospitals: the Adult Psychiatry

Table 1
Demographic characteristics of individuals with ASD and controls. ADOS=Autism Diagnostic Observation Schedule (Lord et al., 2000), SRS=Social Responsiveness Scale (Constantino & Gruber, 2005).

		ASD	Controls	Statistics
All Participants	N =	33	38	
	Age	M = 24.5(7.1–54.45), SD= 13.6	M = 25.0 (7.29–49.5), SD= 14.1	W = 605, p = .81
	Intellectual Quotient	M = 107 (68–145), SD= 19.5	M = 106 (80–125), SD= 12.8	W = 651, p = .78
	Gender (male/female)	27/6	20/18	*
	ADOS	13.3 (4.3)	–	–
	SRS	85.4 (17.7)	–	–
Children only	N =	11	14	
	Age	M = 9.80 (7.1–12.3), SD= 1.87	M = 9.66 (7.29–12.7), SD= 1.35	W = 80, p = .89
	Intellectual Quotient	M = 104 (77–136), SD= 23.7	M = 110 (80–125), SD= 12.96	W = 61.5, p = .41
	Gender (male/female)	7/4	5/9	–
	ADOS	13 (3.4)	–	–
	SRS	85.8 (23.3)	–	–
Adults only	N =	22	24	
	Age	M = 31.8(18.2–54.5), SD= 10.6	M = 33.9(19.4–49.5), SD= 9.64	W = 217, p = .31
	Intellectual Quotient	M = 108 (68–145), SD= 17.5	M = 102 (81–125), SD= 12.0	W = 327, p = .17
	Gender (male/female)	20/2	15/9	–
	ADOS	13.1 (5.0)	–	–
	SRS	82.3 (16.1)	–	–

Department at Albert-Chenevier Hospital, Créteil, France, and the Child and Adolescent Psychiatry Department at Robert-Debré Hospital, Paris, France. Control participants were recruited through advertisements. Prior to their enrollment in the study, control participants were screened to exclude anyone with a history of psychiatric or neurological disorders. All participants were native French speakers and had normal/corrected to normal vision. No between-group difference was found in visual acuity using a procedure adapted from Bach (1996).

The current study was approved by the local Ethics committee (Inserm, Institut Thématique Santé Publique; C07–33; Principal investigators: Prof Leboyer and Prof Bourgeron). All participants provided written informed consent prior to volunteering for this study. The investigation was conducted according to the principles outlined in the Declaration of Helsinki.

2.2. Materials and procedures

Participants sat in front of an LCD laptop monitor at a distance of 60 cm (24") and responded using a modified keypad with only two response keys on the left and right sides. The response keys were labelled with leftward and rightward arrows. The experiment was programmed and displayed using Flash Professional 8®. The experimenter was not visible to the participant during the task.

The task used in this experiment was adapted from Epley, Morewedge, and Keysar (2004), Keysar et al., (2003, 2000). In addition to ToM, this task had obvious verbal and executive requirements that could have limited the diversity of eligible participants and confused the interpretation of results. Therefore, to efficiently test populations with diverse language abilities, we created a computerized version of the task, limiting the verbal component. To control for executive demands of the task, we created a non-social counterpart.

In our computerized task, four objects were randomly disposed on two 3 × 3 (9 compartments) grids (4 objects per grid). On each grid, two to four compartments had a colored background, while the others had a transparent one, making it obvious that some compartments, specifically the colored ones, were visible only to the participant. The objects presented to the participants could be a combination of two shapes (ball or cube), two colors (white or black) and four sizes. The task had four different conditions produced by crossing two factors: the framing of the task (social or non-social) and the congruence (simple or conflict) (see Fig. 1). In the social framing of the task, the director was represented by a schematic character. The character stood in the background, holding an object. Different conditions were defined by the matching between the sample object, held by the character, and the objects displayed in the grids: the sample object matched at least one object in each grid in shape and color, and the decision had to be made based on size. The matching objects were never identical in size, therefore the closest size had to be selected. In the simple condition, the target object was in a compartment with a transparent background and was thus visible to both the participant and director (see Fig. 1A). In the conflict condition, the best matching object was in a compartment with an opaque background, therefore only visible to the participant. For this reason, the target object could not be that one. Consequently, in order to choose the right object, the participant had to take into account the director's perspective (e.g., ignore objects in compartments that had an opaque background) and select the object that was most similar to the sample object that could also be seen by the director (see Fig. 1B). In the non-social framing of the task, the character was replaced by a table, and participants were instructed to ignore objects in compartments that had an opaque background. In the simple condition, the target object was placed in a compartment with a transparent background (see Fig. 1C). In the conflict condition, the best matching object was placed in an opaque background, therefore it could not be the target object. To choose the right

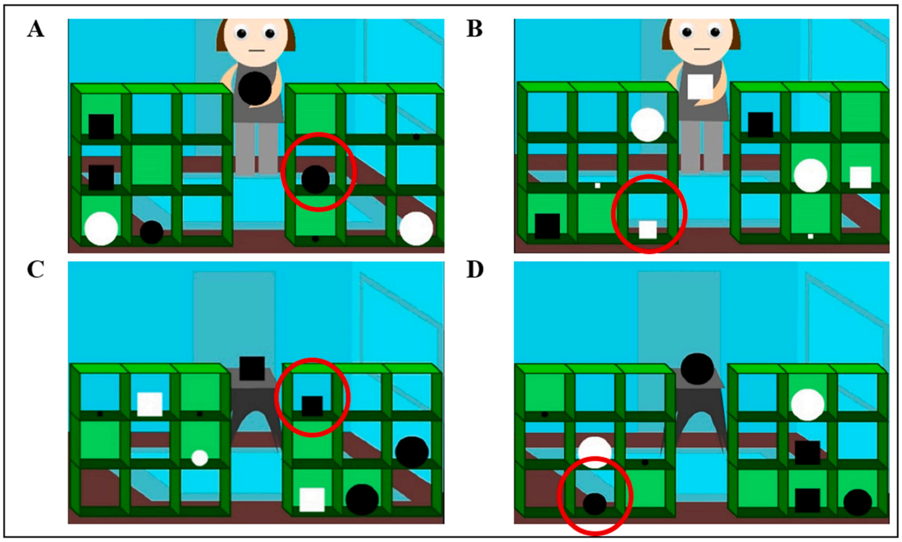

Fig. 1. Sample stimuli used in the social (A & B) and non-social framings (C & D) of our adaptation of the Director's task. The left column depicts the simple condition, and the right column depicts the conflict condition. The red circles are not part of the stimuli. They have been added to the figure to indicate the correct answer.

object, the participant had to ignore the one in the opaque compartment and pick the object that was most similar to the sample object on the table that was also placed in a transparent compartment (see Fig. 1D). Thus, both versions of the task were formally equivalent, and were only differentiated by either having a social component or not. Specifically, both tasks required participants to select similar targets and ignore similar distractors placed in comparable visual settings. The key difference was that in the non-social task, the rule was explicitly given, whereas in the social task, it had to be inferred based on the character's representation and perception of the environment.

The task was embedded in a larger testing session examining perception, social cognition, and executive functions. Before starting the experimental task, the participants completed training trials to ensure that they were able to match the sample object to the target object based on shape, color and size. At the beginning of the training session, participants were given the following pre-recorded verbal, written and illustrated instructions: "Anne holds an object. She wants another object that resembles it as much as possible: it must have the same shape and color and it should be as close as possible in size. Indicate which side Anne will choose to go. The computer will indicate to you each time if your answer was correct. Answer quickly." Along with the instructions, the computer screen displayed a synthetic character (Anne, the director) standing between the two grids holding the sample object. In these trials, no objects were hidden from the director.

After participants completed 5 trials, the first training continued until participants answered at least 70 % of the trials correctly. Following the completion of the first training session, participants were given these additional pre-recorded verbal, written and illustrated instructions: "Certain compartments of the grid are hidden and Anne cannot see them. She doesn't know that the objects are there." Participants were then asked to point to two objects on the screen, one that Anne could see and another that she could not see, to demonstrate understanding that the director had a different perspective from them. All participants answered these questions correctly. In the second training session that followed, some objects were in the hidden compartments and participants now received feedback on their performance. After participants answered correctly on at least 70 % of the trials, they moved on to the task with a social framing. The task consisted of 62 trials and the response time was limited to 3000 ms.

After a delay, during which other tasks were performed, participants completed the task with a non-social framing. The following pre-recorded verbal, written and illustrated instructions were presented to the participants: "There is an object on the table. Choose the object that resembles it most: it must be the same shape and color, and as close as possible by size. Indicate with the left and right arrows on which side the object is located. You must ignore objects in the compartments with green backgrounds. The computer will indicate each time if your answer is right or wrong. Answer quickly." After completing 5 trials, participants continued the training session until they reached a 70 % performance. When participants reached this threshold, the training session ended, and participants were informed that they would no longer receive feedback. The task consisted of 62 trials and the response time was limited to 3000 ms.

2.3. Statistical analysis

Participants' performance, represented by their average percentage accuracy, was measured for each participant in each condition (simple / conflict) and each framing of the task (social / non-social). Our main analysis focused on the interaction between the diagnostic group (ASD / control), the framing (social / non-social) and the condition (simple / conflict). Thus, a three-way mixed analysis of variance (ANOVA) was performed to study the combined effects of three factors on their performance. All assumptions for parametric tests were met. IQ, age group and gender were also included as covariates in the analysis to study the effect of these variables on the performance of both groups.

The p-value for statistical significance was defined as $p < .05$. All analyses were conducted with R statistical computing language (R-Core-Team, 2012).

3. Results

Results are illustrated in Fig. 2. A three-way mixed ANOVA was conducted on performance, with diagnostic group (ASD/Controls), framing (Social/Non-social), and condition (Simple / Conflict) as independent variables. The main effect of diagnostic group was not

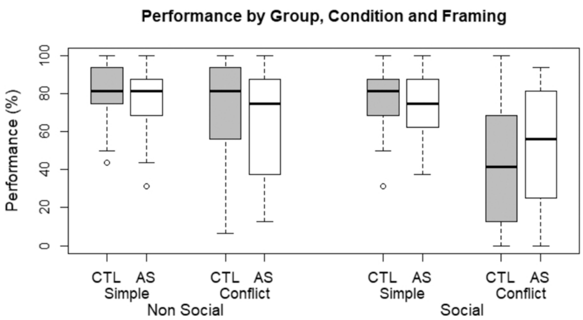

Fig. 2. Average percentage of correct answers for each condition and each group of both social and non-social framings of the task. *AS* autistic group, *CTL* control group. *Error bars* represent SE.

significant, $F(1,69) = 0.20$, $p = .65$, partial $\eta^2 = .00$. The main effect of framing was significant, $F(1,69) = 31.51$, $p < .001$, partial $\eta^2 = .31$, but the interaction between diagnostic group and framing was not significant, $F(1,69) = 3.22$, $p = .08$, partial $\eta^2 = .04$. Besides, the main effect of condition was significant, $F(1,69) = 41.20$, $p < .001$, partial $\eta^2 = .37$, and the interaction between condition and framing was also significant, $F(1,69) = 24.72$, $p < .001$, partial $\eta^2 = .26$. The interaction between diagnostic group and condition was not significant, $F(1,69) = 0.68$, $p = .41$, partial $\eta^2 = .00$. More importantly, the analysis showed a significant interaction between diagnostic group, framing and condition, $F(1, 69) = 4.41$, $p = .04$, partial $\eta^2 = .06$. This result indicated that the interaction among the two factors (framing and condition) was different across the levels of the third factor (diagnostic group). The effect size, indicated by partial η^2, corresponded to a medium effect.

Next, we examined simple effects by decomposing the interaction between the diagnostic group and the framing for the simple condition and the conflict condition. For the simple condition, the main effect of framing was not significant, $F(1, 69) = 2.00$, $p = .17$, partial $\eta^2 = .03$. The interaction was also not significant, $F(1, 69) = 0.01$, $p = .92$, partial $\eta^2 = .00$. However, for the conflict condition, there was a significant main effect of framing, $F(1, 69) = 34.58$, $p < .001$, partial $\eta^2 = .33$, with the social version of the task being significantly more difficult than the non-social version. There was also a significant interaction between diagnostic group and framing, $F(1, 69) = 4.61$, $p = .04$, partial $\eta^2 = 0.06$. This indicates that in the conflict condition, the social version of the task was significantly harder for the control participants than for the autistic participants.

We also examined the interaction between the diagnostic group and the condition of the task for the non-social and the social framing. For the non-social framing, there was a significant main effect of condition, $F(1, 69) = 7.91$, $p = .006$, partial $\eta^2 = .10$, with the conflict condition being more difficult than the simple condition. However, the interaction between diagnostic group and condition of the task was not significant, $F(1, 69) = 0.30$, $p = .59$, partial $\eta^2 = .00$. For the social framing, there was also a significant main effect of condition, $F(1, 69) = 55.47$, $p < .001$, partial $\eta^2 = .45$, with the conflict condition being more difficult than the simple condition. The interaction between diagnostic group and condition of the task was also not significant, $F(1, 69) = 2.91$, $p = .09$, partial $\eta^2 = .04$. Figs. 3 and 4.

When IQ was included in the analysis as a covariate, a main effect on performance could be observed, $F(1, 65) = 12.04$, $p < .001$, $\eta^2 = .16$, with a better performance when IQ was higher. When accounting for age group, a main effect on performance could also be observed, $F(1, 65) = 36.02$, $p < .001$, $\eta^2 = .36$, with a better performance for adults than children, as expected. Results of the main analyses are reported for each age group separately in Table 2 and figures illustrating performance for each age group are available in the Supplementary Materials. We also considered gender, but there was no effect of this variable, $F(1, 65) = 2.09$, $p = .15$, $\eta^2 = .03$. When including IQ, age group and gender in the analysis, the triple interaction between diagnostic group, framing and condition remained significant, $F(1, 67) = 5.19$, $p = .03$, $\eta^2 = .07$.

4. Discussion

The current study examined ToM in adults and children with ASD and control participants using a computerized paradigm based on the Director's task of Keysar et al., (2000, 2003). We adapted the task to be non-verbal and added a non-social control condition. We investigated how diagnostic group (autistic and non-autistic), incongruence between information (simple versus conflict conditions)

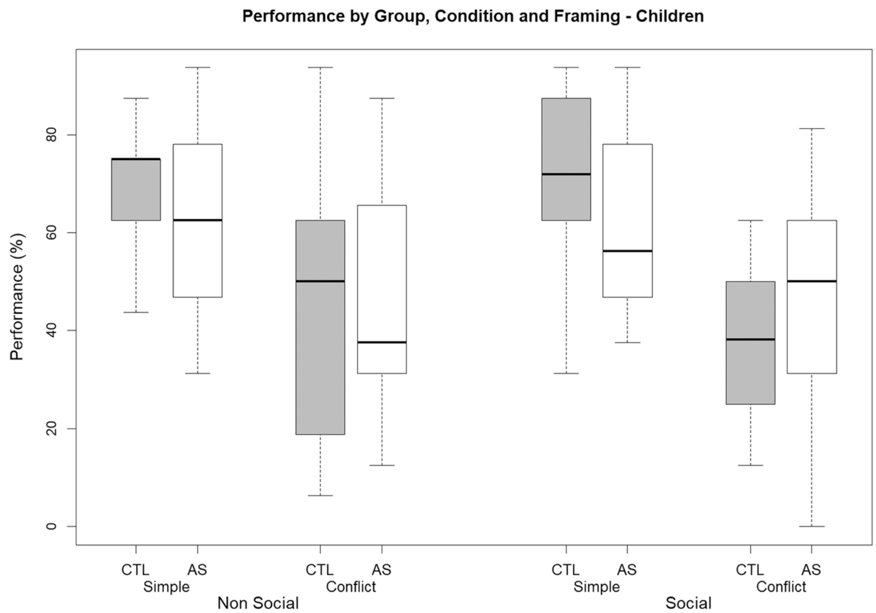

Fig. 3. Average percentage of correct answers for each condition and each group of both social and non-social framings of the task – Children only. *AS* autistic group, *CTL* control group. *Error bars* represent SE.

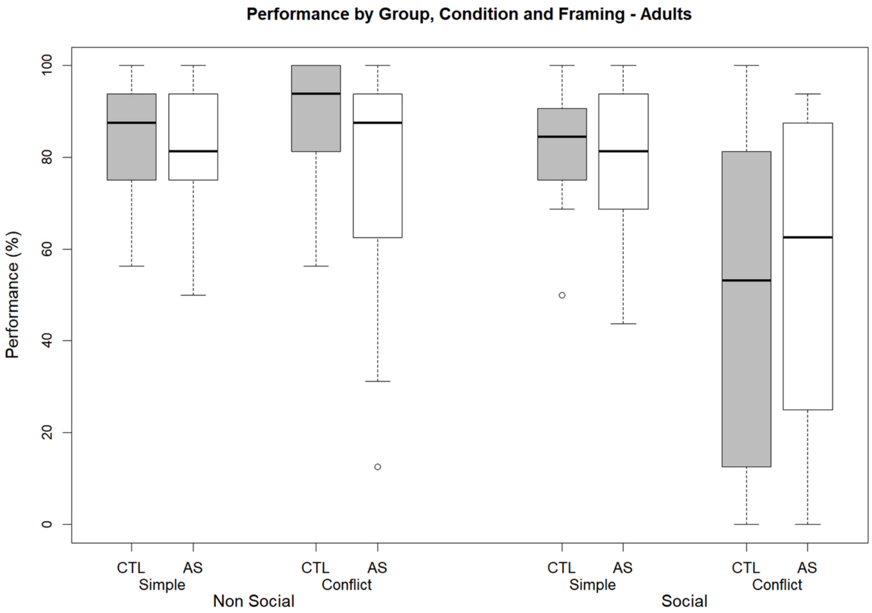

Fig. 4. Average percentage of correct answers for each condition and each group of both social and non-social framings of the task – Adults only. *AS* autistic group, *CTL* control group. *Error bars* represent SE.

and social framing affected performance. Consistent with previous findings that suggest autistic individuals display impaired ToM abilities (Baron-Cohen, 1985; Yirmiya et al., 1998), we hypothesized that conflict would affect the performance of autistic individuals to a greater degree relative to control participants in the social framing of the task, which relies on ToM reasoning. Contrary to our initial prediction, incongruence in social framing affected non-autistic individuals more than autistic participants in the social situation. Both groups performed better in the non-social framing of the task than in the social framing, although this effect was more pronounced for control participants. This suggests that the social framing added difficulty to the task when it was incongruent, particularly for control participants. Furthermore, when included in our analysis, age group and IQ influenced performance, but the interaction between framing, condition and diagnostic group remained significant. As expected, adults performed better than children, which is consistent with the general notion that adults do better than children in most tasks and that ToM skills and other related abilities continue to develop into adolescence.

One previous study (Begeer et al., 2010) showed no advantage for non-autistic over autistic individuals in the Director's task, therefore arguing against the suggestion that autistic individuals have an impaired ToM. Unlike this study, our experiment included a non-social version of the task, which allowed us to compare between strategies used in social and non-social framings, thus allowing us to extend our interpretations.

In fact, one possible explanation for both Begeer et al. results and ours is that autistic individuals might use a common heuristic to solve both social and non-social versions of the task. It could explain why their performance in the social and non-social framings were more similar than control participants. Indeed, a general rule to "ignore objects with a colored background" might have replaced the social heuristic, bypassing the need to constantly refer to the character's perspective and to infer the character's belief throughout the task. This non-social strategy would be similarly used in the social and non-social framing of the task and would rely on domain-general executive processes (e.g., rule learning, inhibition) rather than ToM and metarepresentational skills.

To extract the general rule to solve the task, one may suggest that autistic individuals need to consider what the person knows and should therefore use ToM after all. Indeed, understanding that "seeing leads to knowing" and that "individuals' actions are based on their beliefs and desires" are core components of ToM that are required in the social task. However, this is explicit knowledge that only needs to be used once. The continuous use of ToM (to take into account the director's perspective and beliefs along the entire task) might be optional, since it is possible to initially translate the "social instruction" (to predict the director's behavior) into a non-social rule ("choose the side with the best matching object in a non-colored compartment") once for the entire task. This leads us to argue that although some ToM abilities are required in the task, overall performance of the autistic individuals might have been mostly influenced by general cognitive demands of the task and their ability to extract rules in a social context. On the other hand, participants in the control group would have stuck to a ToM strategy for the entire duration of the task.

This possible interpretation extends the proposition that autistic individuals might pass ToM tasks through the use of different strategies compared to non-autistic individuals (Happé, 1995). The interpretation that control participants in this study relied on ToM reasoning rather than translating the task into a more efficient non-social heuristic is consistent with the trend of non-autistic individuals to spontaneously make social inferences of ambiguous stimuli in various situations (Castelli, Frith, Happé, & Frith, 2002; Pavlova et al., 2017). It also aligns with previous findings that autistic individuals employ a general-purpose heuristic for social and non-social problem-solving, and that this strategy sometimes proves more advantageous in a particular situation (Forgeot d'Arc,

Table 2
Statistics of performance in percentage accuracy for the adapted version of the Director's task for all participants and divided by age group.

			AS		CTL		Statistics		
			Framing		Framing				
			Social	Non-social	Social	Non-social		By condition	With age group and IQ as covariates
All	Condition	Simple	M= 73.30, SD= 18.11	M= 75.95, SD= 17.62	M= 77.65, SD= 16.59	M= 79.93, SD= 13.87	DG: F(1,69)= 0.20, $p = .65$ Fra: F(1,69)= 31.51, $p < .001$ Cond: F(1,69)= 41.20, $p < .001$ AG: F(1,65)= 36.02, $p < .001$ IQ: F(1,65)= 12.04, $p < .001$ Gd: F(1,65)= 2.09, $p = .15$ Cond x Fra: F(1,69)= 24.72, $p < .001$ DG x Fra: F(1,69)= 3.22, $p = .08$ DG x Cond: F(1,69)= 0.68, $p = .41$ DG x Fra x Cond: F(1,69)= 4.41, $p = .04$.	Fra: F(1,69)= 2.00, $p = .17$ DG x Fra: F(1,69)= 0.01, $p = .92$ DG x Fra: F(1,69)= 4.61, $p = .04$	Cond x Fra: F(1,67)= 29.11, $p < .001$ DG x Fra: F(1,67)= 3.75, $p = .06$ DG x Cond: F(1,67)= 0.68, $p = .41$ DG x Fra x Cond: F(1,67)= 5.19, $p = .03$
		Conflict	M= 52.56, SD= 30.63	M= 65.53, SD= 29.98	M= 44.28, SD= 30.87	M=72.86, SD=27.81			
Adults	Condition	Simple	M= 78.69, SD= 15.27	M= 82.10, SD= 12.54	M= 82.81, SD= 11.40	M= 85.42, SD= 11.90	DG: F(1,42)= 0.47, $p = .50$ Fra: F(1,44)= 43.69, $p < .001$ Cond: F(1,44)= 22.45, $p < .001$ IQ: F(1,42)= 6.65, $p = .01$ Cond x Fra: F(1,44)= 34.91, $p < .001$ DG x Cond: F(1,44)= 0.06, $p = .80$ DG x Fra x Cond: F(1,44)= 6.27, $p = .02$		
		Conflict	M=56.68, SD=32.37	M=75.57, SD=27.27	M=47.40, SD=36.49	M=89.06, SD=11.69			
Children	Condition	Simple	M=62.50, SD=19.16	M=63.64, SD=20.31	M=68.80, SD=20.50	M=70.54, SD=12.12	DG: F(1,21)= 0.16, $p = .70$ Fra: F(1,23)= 0.82, $p = .37$ Cond: F(1,23)= 18.81, $p < .001$ IQ: F(1,21)= 6.47, $p = .02$ Cond x Fra: F(1,23)= 0.26, $p = .61$ DG x Cond: F(1,23)= 0.75, $p = .39$ DG x Fra x Cond: F(1,23)= 0.21, $p = .67$		
		Conflict	M=44.32, SD=26.29	M=45.45, SD=25.48	M=38.94, SD=17.53	M=45.09, SD=25.38			

**DG*=diagnostic group; *AG*=Age group; *Gd*=Gender, *Cond*=Condition; *Fra*=Framing; *x* = interaction

Devaine, & Daunizeau, 2020).

Alternatively, it could be suggested that control participants might have misunderstood the initial instructions. This is an unlikely confound, however, because all participants had to complete the training trials with a certain percentage of success, which demonstrated their understanding of the task.

When considering the current results, some limitations should be acknowledged. First, in this experiment, the social and the non-social framings were presented in a fixed order, with the social task presented first. Hence, the order rather than the framing might explain our results. It may explain why performance was globally higher in the non-social than in the social framing (practice effect). However, it is less clear how it could explain the interaction. We anticipated that performing the non-social task first could prompt the participants, especially autistic individuals, to further apply the non-social rule already deduced to the subsequent social task. Therefore, it appeared to us that presenting the social task before the non-social task was the most efficient way of minimizing possible bias. Given the social task was presented first, this carry-over effect cannot be used to explain the higher performance among the ASD group in the social task. Autistic participants are generally expected to have stronger difficulties with a new task (Dawson, Mottron, & Gernsbacher, 2008). In line with this idea, autistic participants would be expected to perform less well than controls in the first task they completed. Nonetheless, in our study, they performed better in the task that was presented first. Moreover, such a practice effect might account for the main effect of framing, but not for the main result of this study, which was the interaction between the diagnostic group, the framing, and the condition of the task.

Another possible limitation of our study is the use of synthetic stimuli and a virtual setting, which might have biased our results. It cannot be ruled out that the use of artificial situations favors the use of a non-social heuristic, whereas a social strategy might be triggered in more explicit social situations. However, participants in the control group seem to have performed both tasks very differently, which strongly suggests they processed the two framings differently. The ASD group also had different performances between the social and non-social tasks, but the difference was smaller. All participants also readily answered preliminary questions showing their interpretation of the character as an agent and their understanding of her perspective and perception. Thus, it is clear that participants in both groups were able to infer mental states to the character, showing the use of the ToM-understanding component. What remains uncertain is whether autistic participants would have maintained a social heuristic if the character had a more realistic appearance. Further research would improve our understanding of this question.

Additionally, our study design limits the generalizability of our results among the autistic population. First, individuals with an intellectual disability or under the age of 6 years were not included. Second, other aspects of heterogeneity such as language level or psychiatric and neurodevelopmental associated conditions were not studied, although they may contribute to variability in results. Autism is increasingly viewed as a diverse group of conditions. It is unclear to what extent our results specifically reflect mechanisms of autism and how results would differ between the ASD group and groups with other additional conditions. As such, the present study can be seen as a proof of concept and opens the door for future studies in larger and more diverse population samples.

Lastly, a word should be said about the sample size and the inclusion of both children and adults in the study. Our study was part of a broader investigation and recruited participants were of all ages. To ensure we had enough power for the analyses, we merged both age groups (children and adults). We are aware that this makes a heterogeneous sample, notably because there is literature showing substantial differences in social cognition between children and adults (Henry et al., 2013). However, when we look at the results, our main result, which is the triple interaction between diagnostic group, framing, and condition, remains significant even after controlling for age group. The sample size was too small to make inferences about the differences between adults and children on referential communication tasks, but we strongly believe that this is an important avenue to explore in the future.

4.1. Implications

Overall, the current study contributes to our understanding of ToM and the diverse strategies employed for social problem-solving in both children and adults with ASD. It also illustrates the importance of controlling for several possible differences when assessing individuals with ASD, given the multifaceted nature of the condition. Altogether, our findings suggest that autistics may be employing different strategies when solving problems, rather than possessing a deficit of certain cognitive functions. A particularly interesting outcome of this study is the idea that depending on certain factors, such as the framing, the use of different strategies may sometimes come with an advantage, and sometimes with a cost.

CRediT authorship contribution statement

Estefania Loza: Investigation, formal analysis, writing - original draft, writing review & editing, visualization, **Frédérique Amsellem:** investigation, project administration, **Tiziana Zalla:** investigation, methodology, project administration, **Ariane Cartigny**: formal analysis, **Marion Leboyer**: project administration, resources, supervision, **Richard Delorme:** Conceptualization, project administration, resources, supervision, writing review & editing, **Franck Ramus:** Conceptualization, methodology, formal analysis, supervision, writing review, **Baudouin Forgeot d′Arc:** Conceptualization, methodology, formal analysis, resources, supervision, writing review & editing, visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rasd.2023.102105.

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