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An eye-tracking study of selective trust development in children with and without autism spectrum disorder

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A B S T R A C T

The purpose of this study was to explore whether children with autism display selectivity in social learning. We investigated the processing of word mappings provided by speakers who differed on previously demonstrated accuracy and on potential degree of reliability in three groups of children (children with autism spectrum disorder, children with developmental language disorder, and typically developing children) aged 4–9 years. In Task 1, one speaker consistently misnamed familiar objects and the second speaker consistently gave correct names. In Task 2, both speakers provided correct information but differed on how they could achieve this accuracy. We analyzed how the speakers' profiles influenced children's decisions to rely on them in order to learn novel words. We also examined how children attended to the speakers' testimony by tracking their eye movements and comparing children' gaze distribution across speakers' faces and objects of their choice. Results show that children rely on associative trait attribution heuristics to selectively learn from accurate speakers. In Task 1, children in all groups preferred the novel object selected by accurate speakers and directly avoided information provided by previously inaccurate speakers, as revealed by the eye-tracking data. In Task 2, where more sophisticated reasoning about speakers' reliability was required, only children in the typically developing group performed above chance. Nonverbal intelligence score emerged as a predictor of children's preference for more reliable

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informational sources. In addition, children with autism exhibited reduced attention to speakers' faces compared with children in the comparison groups.

Introduction

Most situations in which children acquire new words are highly ambiguous. A great number of objects or properties can potentially correspond to an unknown word, especially because the intended referent is almost never presented in isolation. Therefore, it is relatively unsurprising that children take into account various social cues to determine the meanings of new words. For instance, tracking a parent's attention focus is a powerful social cue to determine the reference of her or his utterances (Akhtar & Tomasello, 2000; Baldwin, 1995).

Autism spectrum disorder (ASD) is characterized by impaired social functioning and communication as well as by stereotyped and repetitive behaviors (American Psychiatric Association, 2013). Children with ASD are known to display difficulty in adequately tracking and understanding the communicative intentions of people around them (Baron-Cohen, Leslie, & Frith, 1985; Leekam & Perner, 1991; Yirmiya, Erel, Shaked, & Solomonica-Levi, 1998). It has been suggested that because the ability to map words onto meanings requires attending to social cues, such as the speaker's gaze, social deficits may affect word learning in ASD (Baron-Cohen, Baldwin, & Crowson, 1997; Preissler & Carey, 2005). According to this view, lexical deficits and delays that are often attested in children with ASD could stem from a limited capacity to follow and understand social cues. In line with this hypothesis, unlike their typically developing (TD) peers, children with ASD show a tendency to map words onto referents located within their own attentional focus rather than on those attended by the speaker (Parish-Morris, Hennon, Hirsh-Pasek, Golinkoff, & Tager-Flusberg, 2007; Preissler & Carey, 2005). However, these conclusions have been challenged by a series of more recent eye-tracking studies in which children and adults with ASD proved to be sensitive to the direction of the experimenter's gaze in word-mapping tasks (Bean Ellawadi & McGregor, 2016; Franken, Lewis, & Malone, 2010; Luyster & Lord, 2009; McGregor, Rost, Arenas, Farris-Trimble, & Stiles, 2013; Norbury, Griffiths, & Nation, 2010). Thus, it appears that children with ASD do take speakers into account—to a certain extent, at least—when they acquire and process language.

A promising way to gain better insights into the role that social understanding plays in vocabulary acquisition is to investigate whether social cues in word-learning situations are treated by children in ASD in a flexible way. A child's lexical repertoire is drawn from multiple sources, some of which can be misleading. Speakers may mispronounce some words because they are not fully fluent in the language they speak to the child, others may lack the relevant expertise, and still others may try to deliberately deceive the child or make jokes. This variation in reliability creates pressure to be selective about which information sources are indeed trustworthy. A beneficial strategy for a child who acquires language, thus, would be to rely on the cues offered by reliable sources but to disregard misleading informants. A large body of research on selective learning in TD infants and preschoolers provides evidence for such flexible use of social information (for reviews, see Mills, 2013, and Sobel & Kushnir, 2013). Even very young children frequently modulate their word-learning strategies according to previously demonstrated behaviors of informants; they selectively choose to learn words from speakers who described themselves as knowledgeable (Sabbagh & Baldwin, 2001) or who demonstrated accurate lexical knowledge (Koenig, Clément, & Harris, 2004). Selective learning has been classically studied using a paradigm by Koenig et al. (2004), where children witness (directly or through video recording) two speakers who provide labels for familiar referents, with one speaker systematically mislabeling the objects (e.g., calling a spoon a cup) and another speaker providing the correct labels. Next, children are presented with an unfamiliar object for which both speakers provide conflicting labels; crucially, children appear to display a robust preference for the label used by the accurate speaker. Multiple subsequent studies demonstrated that early selective trust extends beyond the language domain to other learning situations in which an adult's testimony serves as a major source of information (Birch, Vauthier, & Bloom, 2008; Harris, Koenig, Corriveau, & Jaswal, 2018).

Although evidence for the preference for reliable informants in childhood is ubiquitous, explanations for these results in typical development are not yet firmly established and the extent to which they reflect genuine understanding of speakers' trustworthiness is still a matter of controversy (Birch et al., 2017; Poulin-Dubois & Brosseau-Liard, 2016). One possible explanation, in line with sociopragmatic accounts of language learning, would be that, from early developmental stages, children detect and rely on speakers' mental states. Under this line of thought, preschoolers use social information in a flexible way by making inferences about speakers' epistemic states and choosing to trust adults who had demonstrated that they may possess the relevant evidence (Koenig & Harris, 2007; Sobel & Kushnir, 2013).

An alternative—and conflicting—explanation, however, is that selective learning is rooted in a less sophisticated associative mechanism. According to this line of thought, children attribute surface traits to speakers based on their observations of these speakers' previous behavior. It is quite exceptional to witness speakers mislabeling objects around them. Because such behavior may be perceived as highly anomalous, it could be that children simply bypass information coming from inaccurate speakers. Thus, reliable speakers would be held generally knowledgeable—rather than situationally informed—because they do not exhibit the odd behavior characteristic of inaccurate speakers (Lucas & Lewis, 2010).

Whereas sociopragmatic explanations entail that children genuinely process speakers' knowledge states, associative responses rest on nothing more than simple global rejection of the unconventional behavior demonstrated by inaccurate speakers. Children's preference for the information associated with accurate speakers would not arise from rational inference about their expertise but rather is simply induced by a rejection of inaccurate speakers. Thus, even though a preference for accurate speakers may misleadingly appear as a rational choice, it may simply result from a surface trait attribution that leads to the rejection of inaccurate speakers. In other situations, where children erroneously rely on irrelevant attributes, the superficial trait attribution process may result in irrational trusting behavior. For instance, preschoolers were found to selectively learn words from attractive, nice, and strong speakers rather than from unattractive, mean, and weaker ones even when the former were wrong (Bascandziev & Harris, 2014; Fusaro, Corriveau, & Harris, 2011; Landrum, Mills, & Johnston, 2013).

To assess the potential implication of mental state understanding in selective learning, one could examine correlations between children's performance on standard theory of mind tasks and tasks on speakers' reliability. However, currently available results are inconclusive, with some researchers reporting moderate correlations (Brosseau-Liard, Penney, & Poulin-Dubois, 2015; DiYanni, Nini, Rheel, & Livelli, 2012) and others finding no correlation at all (Brosseau-Liard, Iannuzziello, & Varin, 2018; Pasquini, Corriveau, Koenig, & Harris, 2007). To investigate the impact of speakers' trustworthiness on language acquisition in ASD, a clinical group with robustly documented difficulties in perspective taking and mentalizing may provide more direct insight into the nature of selective learning.

Recall that there is ample evidence that individuals with ASD have limited abilities in tracking the mental states of others during interaction. If selective learning is rooted in mentalizing abilities, as held by the proponents of sociopragmatic theories, then one should expect children with ASD to fail to display selective learning based on their misunderstanding of speakers' epistemic statuses. However, if children's learning strategies in tasks where they prefer learning from previously accurate speakers rely on a more general associative mechanism, then children with ASD could prove to be as sensitive as TD children to speakers' previous accuracy.

It is also possible that in some situations of social learning, TD children spontaneously engage in mental state reasoning but also use less sophisticated mechanisms in other situations. A dual-processing account of selective trust proposes that children simultaneously use two kinds of underlying cognitive process: one unsophisticated and fast mechanism that is driven by trait attribution and one slow process that requires situational inference-making strategies (Hermes, Behne, & Rakoczy, 2018). Importantly, these two mechanisms may coexist and operate in parallel as determined by situational context; it is also likely that a more sophisticated process will appear later during child development.

One way to determine whether a nuanced understanding of epistemic reasoning is available to young children is to expose them to speakers who demonstrate the same degree of accuracy on the surface but differ in the way they achieve this accuracy. For example, Nurmsoo and Robinson (2009) found that preschoolers fail to take into account the difference in information access between two speakers. In this study, children showed no preference for speakers who had excusable reason for erring (blindfolded speakers) over speakers who had no obvious excuse for being inaccurate. However, in another study (Kondrad & Jaswal, 2012), 4- and 5-year-old children were found to overlook semantic errors that were closer to being correct (e.g., the mislabeling of a comb as a brush rather than as a thunderstorm) when the speaker's errors could be excused. Likewise, Einav and Robinson (2011) reported that by 4 years of age children are sensitive to the conditions under which accuracy is achieved. In this study, children were presented with two speakers, both of whom correctly named familiar objects; however, whereas one speaker needed help to do so, the other one reached correct labels without being helped. The authors found that 4-year-olds, but not 3-year-olds, displayed a preference for the novel labels that were offered by the latter speaker. Age was also found to predict children's ability to prioritize the accuracy of a speaker over the speaker's confidence in learning situations (Brosseau-Liard, Cassels, & Birch, 2014). These results suggest that the mechanisms involved in selective learning may be situation dependent and evolve across development, with more sophisticated inference-based mechanisms appearing only later.

Nuanced social selective learning may also remain challenging for younger preschoolers because in such tasks children would need to make inferences at two parallel levels (Landrum, Eaves, & Shafto, 2015). Learning accurate information from others requires drawing inferences both about speakers' state of knowledge and about the information they provide. In other words, learners must apply their assumptions about the speakers' epistemic state to make inferences about object–referent pairs. One could argue that failure to learn words selectively by younger children in more complex contexts does not follow so much from a difficulty to evaluate speakers' epistemic statuses as from a difficulty to apply this information while reasoning about which of two available referents should be associated with a novel word.

Independent of the reason why sophisticated processing of social cues is not entirely in place in younger TD children, one should expect it to be unavailable to children with ASD. A number of studies on language processing reported significant impairments in context-based inferences in ASD (Bodner, Engelhardt, Minshew, & Williams, 2015; Dennis, Lazenby, & Lockyer, 2001; Happé, 1994). In addition to difficulties in drawing inferences about intentions or mental states (Scott & Baron-Cohen, 1996), some studies have also reported impaired processing of causal links in nonsocial events in autism (Mason, Williams, Kana, Minshew, & Just, 2008). Difficulties in drawing context-based inferences should prevent children with ASD from taking into account nuanced differences in speakers' behavior and associating it with various degrees of trustworthiness.

To get more insight into the mechanisms involved in social selective learning, it is important to use methods that would not only determine whether children discriminate between reliable and less reliable speakers but also reveal, through a dynamic exploration of social cue processing, how children reach their decisions. To that end, behavioral data on children's performance should be complemented by visual exploration patterns. It is widely acknowledged that visually exploring people's faces provides powerful social cues. For instance, one study found that 14-month-old infants more readily followed the gaze of a reliable experimenter versus an unreliable one (Chow, Poulin-Dubois, & Lewis, 2008). Therefore, eye tracking constitutes a promising tool to study selective trust.

Eye tracking is especially relevant for our research question because numerous studies reveal that individuals with ASD attend less than their TD peers to social stimuli, especially when there is competition between social and nonsocial information (Kikuchi, Senju, Tojo, Osanai, & Hasegawa, 2009; Moore, Heavey, & Reidy, 2012; Riby & Hancock, 2009). Furthermore, even when overall distribution of attention to social and nonsocial stimuli is within the typical range, the time course of gaze shifts to important social cues may still significantly differ between individuals with and without ASD (Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Kikuchi et al., 2009).

That said, in studies that explored visual attention in referential tasks, no significant group differences were found in the amount of attention allocated to social (eyes and mouth of a speaker) versus nonsocial (target object and distractor) areas of interest between children with ASD and TD children (Norbury et al., 2010; Tenenbaum, Amso, Abar, & Sheinkopf, 2014). However, the gaze exploration of social and nonsocial information in a more complex word-learning situation—when two speakers produce conflicting information—has not yet been studied. Furthermore, according to a recent meta-analysis, high social content (corresponding to a higher number of people involved in an observed interaction) has been found to be a strong predictor of diminished social attention in autism (Chita-Tegmark, 2016). One could expect that children with ASD would be less attracted by socially relevant information in complex social scenes and, for this reason, would experience difficulties in forming expectations about speakers' competence.

Another factor that can help to elucidate the relationships between sociopragmatic processes and selective learning in autism is the choice of control groups. The most widespread method in research on ASD is to recruit comparison groups of TD individuals matched on chronological age and/or cognitive abilities—in spite of the fact that children with ASD often exhibit a significant delay in language acquisition. Children with developmental language disorder (DLD),[1] who usually have vocabulary deficits comparable to those observed in children with ASD, arguably constitute a more adequate comparison group for studying word learning in autism. Moreover, such a comparison may help to elucidate the role of attention to social information in selective learning given that children with DLD have been found to privilege socially relevant information in the same way as their TD peers (Hanley et al., 2014). At the same time, children with DLD may exhibit important sociocommunicative impairments usually associated with poor language skills (Botting & Conti-Ramsden, 2008; St Clair, Pickles, Durkin, & Conti-Ramsden, 2011). Given that both children with ASD and children with DLD share similar communication difficulties but are likely to differ in their processing of social cues, comparing these populations may increase our understanding of the mechanisms that support selectivity in social learning.

The current study was designed to explore the role of social-pragmatic reasoning in selective learning tasks in both typical and atypical development. Tasks on selective trust have been extensively implemented with TD children and infants, but to the best of our knowledge no study has yet addressed this issue in children with ASD.

Our aim here was to investigate whether children with ASD can selectively use social cues for word learning. We also considered two alternative theoretical accounts of social selective learning: one that explains early sensitivity to information sources, in typical development, by a precocious capacity to reason about knowledge states of speakers and the other that explains this sensitivity by a general surface trait attribution mechanism. One way of adjudicating between these two positions is to investigate selective social learning in children who show impoverished social-pragmatic processing. The past 25 years of research yielded ample and robust evidence that individuals with ASD present such a clinical profile. Given the relatively uncontroversial presence of difficulty in reasoning about other people's mental states in ASD, two antagonistic predictions may be drawn from the two accounts of selective learning just evoked. First, consistent with the first (inference-based) account, children with ASD should not be able to use social cues in a flexible way in word-learning situations; thus, they should display no preference for word–object mappings offered by a previously accurate speaker and would perform at chance in "classic" tasks on selective trust. Second, consistent with the second (associative surface trait attribution) account, children with ASD may display selective social learning, suggesting that it does not depend on the kind of pragmatic and mentalizing skills whose deficits are otherwise attested in this population.

As seen above, a conservative interpretation of selective learning is that mental state reasoning is not required in all word-learning situations, so that young children may avoid learning from inaccurate speakers through a less sophisticated associative mechanism. Therefore, we explored children's performance in two different word-learning situations. In a first task, we used a set of short videos based on a classic selective trust experiment with two speakers, one of whom applies familiar nouns to correct objects and the other of whom does so systematically to incorrect objects. In the second task, we used a scenario similar to that of Einav and Robinson (2011), which requires reasoning about speakers' previous behavior. In this scenario, both speakers give correct answers, but the reliability of the speakers can be assessed through the way these accurate responses were achieved; in familiarization trials, one of the speakers is systematically assisted by a third party, whereas the other speaker always makes her lexical choices by herself. In this scenario, to evaluate the degree of speakers' poten-

[1] As recommended by Bishop, Snowling, Thompson, and Greenhalgh (2017), we use the term developmental language disorder (DLD) instead of the previously used term specific language impairment (SLI).

tial accuracy, children must build a model of speakers' epistemic status based on the interaction that these speakers previously had with the third party. Therefore, sensitivity to speakers' competences in such a task cannot be explained by the surface trait attribution mechanism. Moreover, an above chance performance in this task would strongly suggest a capacity of genuine social-cognitive reasoning. We predicted, therefore, that children with ASD, but not TD children, would fail to display selective learning in this complex situation.

We also conducted an exploratory study of how children allocate attention during learning. We reasoned that children might differentiate between speakers before they make their lexical decisions by diverting their attention away from the demonstration made by the unreliable speaker. To this end, we compared gaze fixation patterns associated with conflicting mappings made by each speaker during test trials in two tasks. We predicted that if children with ASD fail to differentiate between the two speakers in the tasks, then their patterns of gaze distribution should differ from the gaze allocation in the DLD and TD groups. In addition to examining whether children's gaze patterns are predicted by the previously demonstrated reliability of speakers, this design provides an excellent opportunity to explore whether attention to social information—the speaker's face—during a dynamic learning scenario is reduced in the ASD group as compared with the DLD and TD groups.

In sum, if selective social learning requires understanding mental states, then it should be impaired in children with ASD but not (or at least not to the same extent) in children with DLD and in TD children. However, one should not expect children with ASD to fail to discriminate between speakers based on their previous accuracy if such discrimination is associated with surface trait attribution. To the best of our knowledge, no study has attempted to analyze distribution of attention to faces of speakers producing conflicting information in word-learning situations. We fill this gap and reason that the patterns of attention allocation should help to understand the final lexical choice made by children in different groups. Children's attention to the information provided by speakers may vary as a function of speakers' previous accuracy; children should attend more to the novel object–word pairings associated with a previously accurate speaker. We also expected that the pattern of attention distribution would be associated with group performance; if children with ASD fail to use the speaker's epistemic status in learning new words, then this failure would be associated with an atypical attention distribution pattern.

Method

Participants

Children with DLD and children with ASD were recruited from special school departments for children or by referral from local providers. Diagnosis in the ASD group was confirmed by administration of the Autism Diagnostic Observation Schedule (ADOS) to the children (Lord et al., 2000) by an accredited assessor. All participants in the ASD group met the ADOS cutoff for autism. Children in TD group were recruited from mainstream primary schools. The absence of ASD in both groups of children with DLD and TD children was confirmed by the administration of the Autism Diagnostic Interview–Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994) to their parents by an accredited ADI-R and ADOS assessor. All the children with TD and DLD scored below the exclusionary cutoffs for at least two content areas. Parental informed consent was collected for each child.

Our final sample consisted of 25 children with a confirmed diagnosis of ASD (mean age = 6.9 years, range = 4.1–9.0), 32 children with DLD (mean age = 7.3 years, range = 5.1–9.4), and 20 TD children (mean age = 7.1 years, range = 4.1–8.8). An analysis of variance (ANOVA) indicated no significant differences in age among the groups, $F(2, 74) = 0.31$, $p = 0.73$. One child in the ASD group and 4 children in the DLD group were excluded due to technical issues and experimenter errors.

Procedure

Participation in this study involved two experimental sessions. In a first session, all participants underwent cognitive and language testing. Nonverbal IQ was measured by the composite score of four intelligence subtests (Sequential Order, Form Completion, Classification and Analogies, and Figure Ground) of the Leiter International Performance Scale–third edition (Leiter-3; Rold, Miller, Pomplun, & Koch, 2013), which is particularly suited to assess nonverbal cognitive abilities in populations with atypical development. Receptive vocabulary was measured by the French version of the Peabody Picture Vocabulary Test–Revised (Dunn & Theriault-Whalen, 1993). All children included in the final sample were considered cognitively able, achieving IQ scores of 70 or above. Table 1 provides the descriptive statistics for all groups. There was a statistically significant diagnostic group effect for nonverbal cognitive abilities, $F(2, 74) = 15.01$, $p < 0.001$, and receptive vocabulary, $F(2, 74) = 15.76$, $p < 0.001$. Post hoc Tukey HSD (honestly significant difference) tests revealed that the TD group scored significantly above the ASD and DLD groups on verbal and nonverbal scores (*ps* < 0.01). The ASD and DLD groups did not significantly differ on both measures.

During the second session, two tasks were performed in a counterbalanced order. For each task, drawings of six familiar objects and two novel objects were used as the target objects. Within each task, two sets of live video recordings of a female adult and a male adult were created. In one set (Set 1), the female adult was acting as a "reliable speaker" and correctly designated familiar objects; in the second set (Set 2), she acted as an "unreliable speaker" and failed to correctly designate familiar objects. Half of the children were assigned to Set 1 and the other half to Set 2. Children for whom the reliable speaker was a female figure in the first task saw a set with a male figure as a more reliable speaker in the second task. This was done to minimize the impact of potential transfer of information about speakers' reliability from one task to another. Two different pairs of adults were filmed for each task.

Eye-tracking measures were collected using a portable Tobii X2-60 eye tracker sampling at 60 Hz. The device was attached underneath a 16-inch computer touchscreen display (full-screen mode was used with a resolution of 1920 × 1080 pixels). Participants were seated approximatively 60 cm from the screen. Their gazes were calibrated using 5-point infant mode procedure before each task.

Scenario of Task 1

Children first watched a video in which the two speakers introduced themselves (e.g., "Hi! My name is Julie," "Hi! My name is Philippe"). Next, images of two familiar objects were displayed on the screen accompanied by a request to designate one of these two objects (e.g., "Where is the truck?"). One of the speakers was asked by her or his name to answer; that speaker was followed by the second speaker (e.g., Julie's turn and then Philippe's turn). Finally, children were invited to touch an object ("It's your turn"). The two speakers, and then children, were asked to identify the

Table 1
Descriptive statistics in ASD, DLD, and TD groups.

	ASD (*n* = 25; 7 girls) [mean (*SD*)] (range)	DLD (*n* = 32; 12 girls) [mean (*SD*)] (range)	TD (*n* = 20; 12 girls) [mean (*SD*)] (range)
Chronological age (years)	6.9 (1.7) (4.1–9.0)	7.3 (1.3) (5.1–9.4)	7.1 (1.6) (4.1–8.8)
Nonverbal IQ	92.66 (14.11) (71–120)	96.03 (11.59) (70–119)	109.54 (10.02) (78–126)
Vocabulary score	87.4 (20.6) (65–124)	94.65 (15.2) (66–113)	113.63 (15.88) (95–136)
ADOS total score	14.0 (4.6) (9–22)	NA	NA
ADI-R social interaction	NA	2.6 (2.3) (0–7)	1.6 (1.3) (0–6)
ADI-R communication	NA	3.2 (1.7) (0–8)	0.9 (0.9) (0–3)
ADI-R restrictive and stereotyped behavior	NA	0.5 (0.5) (0–2)	0.4 (0.5) (0–1)

Note. ASD, autism spectrum disorder; DLD, developmental language disorder; TD, typically developing; ADOS, Autism Diagnostic Observation Schedule; ADI-R, Autism Diagnostic Interview–Revised, NA , not applicable.

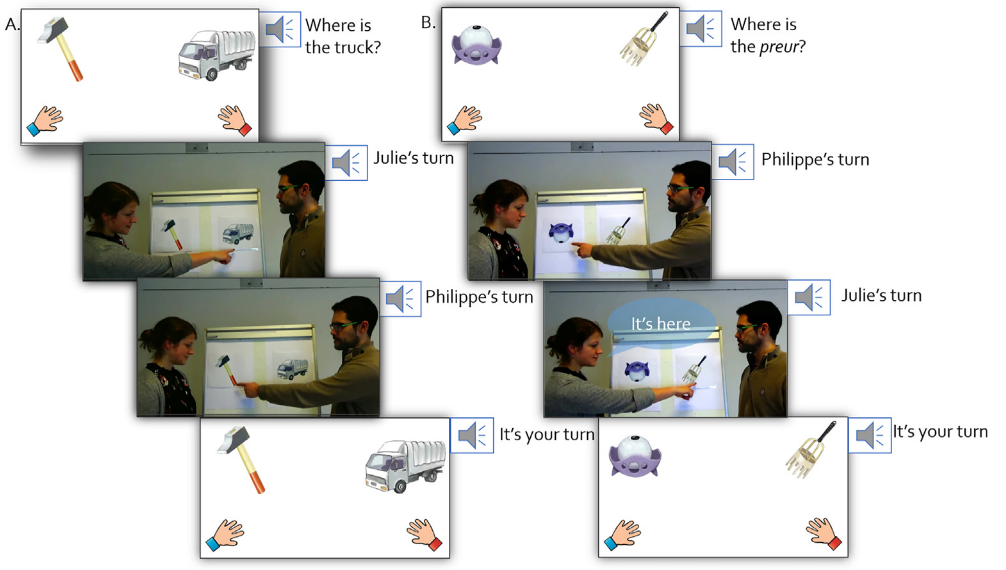

Fig. 1. Structure of the scenario used in Task 1. (A) Scenario of one of three familiarization trials. (B) Test trial for which eye-tracking data were analyzed. The original instructions are translated from French.

object that they thought corresponded to a pseudoword. Fig. 1 shows the temporal course of one version of the task with the familiarization and test trials. Female and male speakers acted alternatively as reliable and unreliable speakers in two sets, and the order of speakers was counterbalanced across sets. Positions of all pictures on the screen remained identical across sets. There were three familiarization trials with both speakers, so that each speaker performed a mapping with familiar objects three times before the test trial.

Scenario of Task 2

Two sets of videos were created for Task 2 using the same counterbalancing method as the one described above for Task 1. The structure of this task was similar to the one used in Task 1. However, in this second task, familiarization trials featured three characters: two adults and a puppet. The adults introduced themselves by their names (e.g., "Hi! My name is Pierre," "Hi! My name is Sophie"); the puppet introduced itself as follows: "Hi! My name is Ted, and I know a lot of things!" Next, as in Task 1, two familiar objects were displayed along with a request to designate one of them. Fig. 2 contains descriptions of the scenarios used in the familiarization trials in Task 2.

Each adult was solicited, in turn, to show the corresponding object; each time, the puppet asked the adult whether she or he needed help. The less reliable speaker always answered that she or he would need help; the puppet then moved to the part of the screen where the correct object was located, and the adult eventually pointed at it. The more reliable speaker always replied, "No, thank you, I'll keep thinking," and after a short hesitation designated the correct object. This last feature ensured that the more reliable adult did not appear to be more confident than the less reliable adult because confidence is another cue children may rely on during selective learning (Brosseau-Liard et al., 2014; Matsui, Yamamoto, & McCagg, 2006). Before the test trial was launched, children witnessed the puppet leaving the scene and were told that it could no longer help the players. The structure and temporal course of the test trial were identical to those of Test 1. Three familiarization videos per speaker were shown, so that six different familiar objects in total were indicated by both speakers; the order of these videos was randomized.

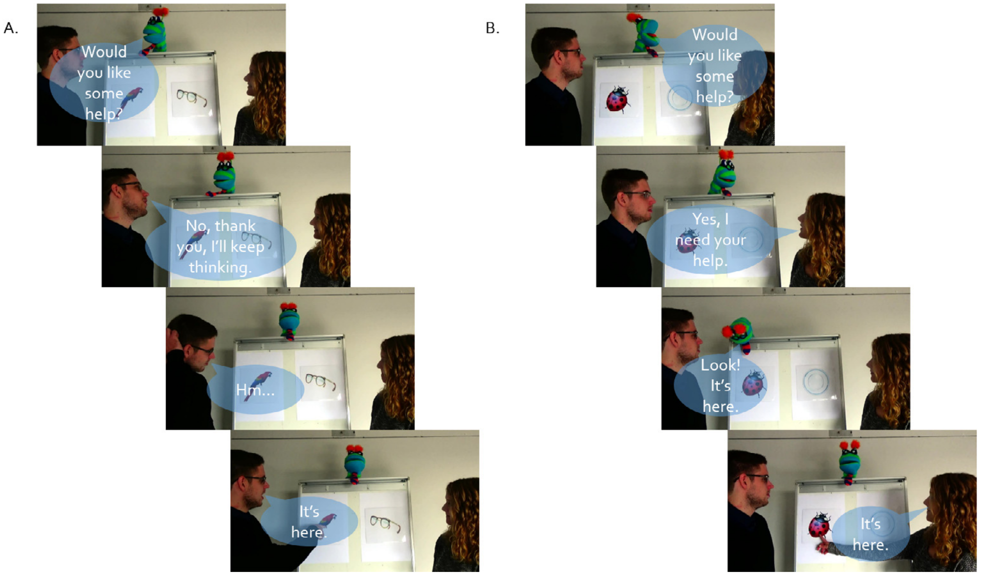

Fig. 2. Scenario of two familiarization trials in Task 2. (A) Trial with a more reliable speaker. (B) Trial with a less reliable speaker. The original instructions are translated from French.

Data preparation

Eye-tracking data were analyzed for the test trials in both tasks. Our aim was to explore attention allocation patterns during the word mappings made by reliable and unreliable speakers. We focused on analyses of two *segments* of the test trials corresponding to the 2-s intervals during which each speaker showed one of two referents on the board. The beginning of each segment of interest was identified as the onset of the adult name when the adult was solicited to provide her or his answer (e.g., "It is Julie's turn") separately for each speaker and set.

To be able to reach valid and reliable conclusions based on the eye-tracking data, participants needed to have attended to both segments of interest for a substantial amount of time. To this end, we defined a 70% available recording threshold and included in final analyses only those recordings for which participants had at least 1400 s of dwell time on the screen detected for each segment of interest.

In each segment of interest, we defined four areas of interest (AOIs). Two AOIs were nonsocial areas that corresponded to two images of objects displayed on the board, and two were dynamic social AOIs that were adjusted frame by frame to capture all fixations on the faces of speakers (see Fig. 3).

Results

Task 1

All analyses were conducted using R (R Core Team, 2018). Generalized linear models (GLMs) were fitted using the *glm* function and linear mixed-effects models were fitted using the *lmer* function in the lme4 library of R (Bates, Maechler, Bolker, & Walker, 2015).

We began by analyzing the accuracy of participants' responses. In total, 16 of 20 children in the TD group, 25 of 32 children in the DLD group, and 18 of 24 children in the ASD group pointed at the object selected by the reliable speaker at the end of the test trial. Response accuracy in each group was significantly above chance ($p < 0.05$, binomial test).

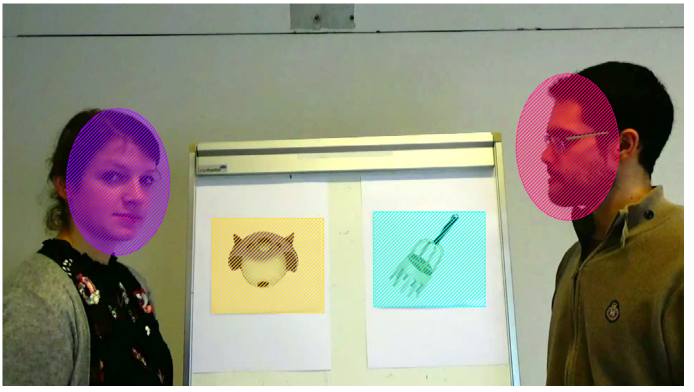

Fig. 3. Screenshot of a test trial video with highlighted areas of interest.

All tested children in our sample were cognitively able and displayed a sufficient verbal comprehension level; nevertheless, there was a significant difference in nonverbal and verbal IQs between each clinical group and the group of TD children. That is why we also explored whether receptive vocabulary and nonverbal IQ were predictors of children's choice. Because prior research has found that children's selectivity may also vary as a function of age, age was also included as a predictor in these analyses.

A GLM was run with group, age, receptive vocabulary, and nonverbal IQ as predictors and the binomial measure of preference as a response variable. Analyses revealed significant main effects of receptive vocabulary, $\chi^2(1) = 8.14$, $p = 0.004$, and nonverbal IQ, $\chi^2(1) = 10.51$, $p = 0.001$. The models containing age, $\chi^2(1) = 2.26$, $p = 0.92$, and group, $\chi^2(2) = 0.16$, $p = 0.13$, as fixed effects did not differ significantly from the null model. Therefore, at the group level, children with ASD, children with DLD, and TD children performed equally well. Unsurprisingly, failures in this task were associated with low verbal and nonverbal IQ skills.

Next, we explored the pattern of children's attention allocation in the test trial for two segments of interest that corresponded to the demonstrations performed by the reliable and unreliable speakers. A sufficient quantity of eye-tracking data for each segment of interest (>70%) in Task 1 was available for 15 children in the TD group ($M = 95.5$, $SD = 8.7$), 20 children in the DLD group ($M = 94.2$, $SD = 9.5$), and 18 children in the ASD group ($M = 89.2$, $SD = 11.3$). Within each segment, the object that was shown by a speaker was coded as the *indicated object* and the speaker who performed the mapping was coded as the *active speaker;* the second object and second speaker were coded as the *other object* and *inactive speaker*, respectively. Speakers and objects were counterbalanced across these AOIs in two segments according to the roles performed by the speakers.

We calculated proportion of fixations for each AOI in the two segments of interest by dividing the total number of fixations within each AOI by the total number of fixations on the screen (see Fig. 4). We analyzed gaze data with linear mixed-effects models with by-participant random intercepts. We built a linear mixed model with proportion of fixations as the predicted variable and AOI as the predictor variable. We performed a likelihood ratio test of the model containing the fixed effect of AOI against a null model, which had the same random effects structure but did not include the fixed AOI factor. A significant effect of AOI was detected, $\chi^2(3) = 188.7$, $p < 0.001$. By contrast, neither the fixed group effect, $\chi^2(2) = 0.97$, $p = 0.61$, nor the AOI × Group interaction, $\chi^2(6) = 5.21$, $p = 0.51$, improved the fit relative to the null model.

There was an interaction between segment (reliable vs. unreliable speaker) and AOI, $\chi^2(3) = 46.38$, $p < 0.001$. Fig. 5 illustrates the proportion of fixations, as estimated by this model, by AOI in two segments of interest corresponding to alternative mappings made by a reliable speaker and an unreliable speaker. As can be seen from this figure, the distribution of fixations toward objects and speakers was closely associated with speakers' prior behavior. We conducted post hoc pairwise comparisons using

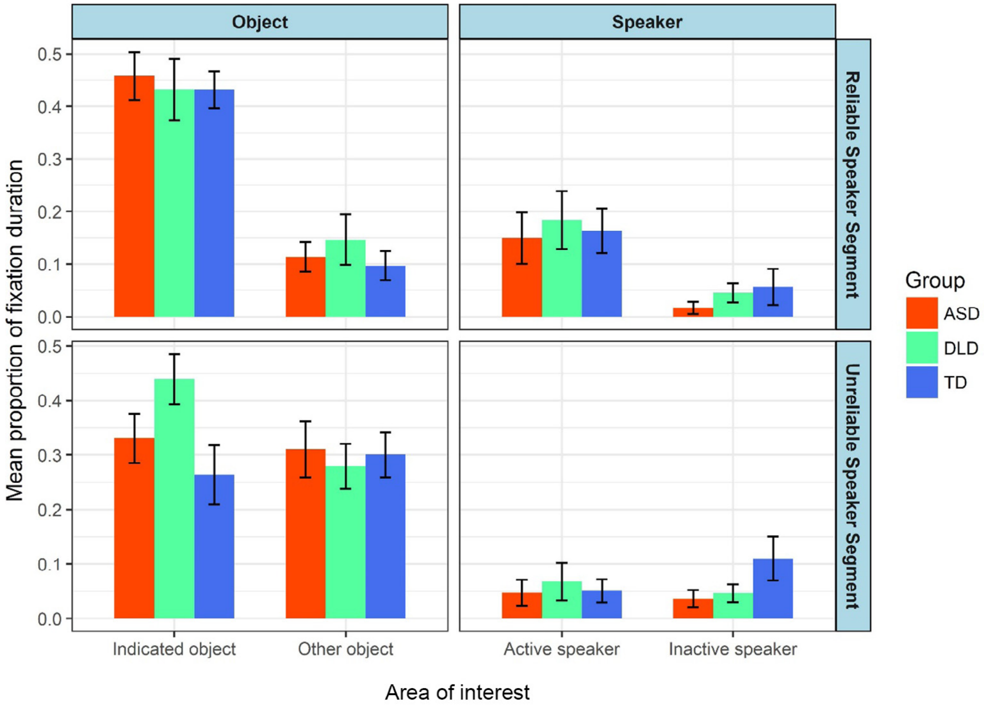

Fig. 4. Task 1: Mean proportions of fixation duration across four areas of interest per segment by group. Error bars display standard errors of the means. ASD, autism spectrum disorder; DLD, developmental language disorder; TD, typically developing.

the *lsmeans* function of the R package lsmeans (Lenth, 2016). Children looked more at the reliable speaker's face compared with the unreliable speaker's face in the segment where the reliable speaker pointed at the novel word referent ($\beta = 0.12$, $t = 3.92$, $p < 0.001$).

No such difference was detected in the segment where it was the unreliable speaker who pointed at the novel word referent ($\beta = 0.01$, $t = -0.16$, $p = 0.99$). Children looked more at the object shown by the reliable speaker, as compared with the other object, when this speaker pointed at it ($\beta = 0.31$, $t = 9.82$, $p < 0.001$). However, they did not display such a preference in the unreliable speaker segment ($\beta = 0.05$, $t = 1.75$, $p = 0.29$).

Finally, recall that children in the ASD group can be expected to exhibit a pattern of fixation distribution in two segments of interest that is different from children in the TD and DLD groups. To assess this possibility, we considered a model containing an AOI, segment, and group interaction, but this triple interaction did not improve the fit relative to the model with the AOI × Segment interaction, $\chi^2(11) = 13.05$, $p = 0.52$).

To sum up, we found that children in all groups performed above chance in Task 1 and that children's performance in this task correlated with verbal and nonverbal IQ. Children in all groups preferred to encode novel word–referent pairs following cues offered by reliable speakers. Furthermore, by exploring patterns of attention allocation in a word-learning situation with conflicting testimony provided by previously accurate and inaccurate speakers, we detected a significant AOI × Segment interaction, indicating that children's visual attention was determined by speakers' prior accuracy. Children with ASD tracked speakers' responses in the test trial in the same way as children in both the DLD and TD groups, suggesting that children with ASD may avoid learning from inaccurate speakers.

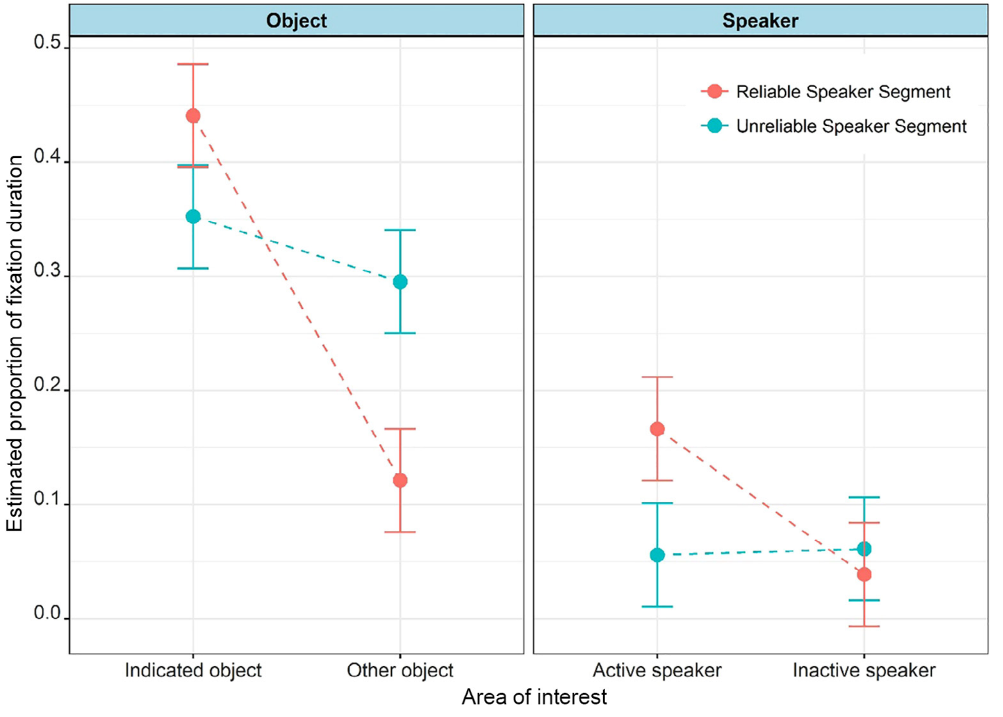

Fig. 5. Task 1: Estimated proportions of fixation across areas of interest in two segments corresponding to word–object mappings by a reliable speaker and by an unreliable speaker. Vertical bars correspond to 95% confidence intervals.

Task 2

In this task, we coded as *more reliable* the segment corresponding to a demonstration performed by a speaker who could show a correct familiar object without being systematically helped by the puppet, whereas the segment of a speaker who was systematically assisted by the puppet was coded as *less reliable.*

First, we analyzed the distribution of children's responses in the test trial. Responses of 1 child in the TD group, of 5 children in the DLD group, and of 4 children in the ASD group were not registered at the end of the test trial due to technical errors or because children exceeded a 15-s interval to make their decision. In total, 17 of 19 children in the TD group, 13 of 28 children in the DLD group, and 12 of 21 children in the ASD group selected the correct object. Performance of children in the TD group demonstrated their preference for an object shown by a more reliable speaker ($p = 0.01$, binomial test). Children in both the ASD and DLD groups failed to demonstrate such a preference and performed at chance in the task. We further compared the distribution among groups with Fisher's exact test for count data and found that distribution of responses in the TD group significantly differed from those in DLD and ASD groups ($p = 0.01$).

We were further interested in how individual differences in age, receptive vocabulary, and nonverbal IQ might relate to the task performance. We fitted these variables to the GLM models. Analyses revealed significant main effects of group, $\chi^2(2) = 9.19$, $p = 0.01$, of receptive vocabulary, $\chi^2(1) = 3.86$, $p = 0.04$, and of nonverbal IQ score, $\chi^2(1) = 11.51$, $p < 0.001$. No effect of age was detected, $\chi^2(1) = 0.52$, $p = 0.46$. Next, we investigated whether group effect was detectable while controlling for individual differences in children's receptive vocabulary and nonverbal IQ. A model with the added group variable did not differ significantly from the model with only receptive vocabulary and nonver-

Table 2
Fixed effects in a general linear model fitting accuracy of children's response in Task 2.

Effect	β	*SE*	*z Value*	*p*
Intercept (ASD group)	−4.45	2.27	−1.96	
Nonverbal IQ score	0.05	0.02	2.11	0.03*
Receptive vocabulary	0.006	0.01	0.38	0.70
ASD compared with DLD	−0.45	0.62	−0.72	0.46
ASD compared with TD	0.89	0.91	0.97	0.32

Note. ASD, autism spectrum disorder; DLD, developmental language disorder; TD, typically developing.
* $p < 0.05$.

bal IQ as predictors, $\chi^2(2) = 3.20$, $p = 0.20$. As can be seen from the summary of this model in Table 2, nonverbal IQ emerged as a unique predictor of children's selectivity.

Next, we explored the pattern of children's attention allocation in the test trial for the two segments of interest (i.e., mappings by the more and less reliable speakers). Sufficient quantity of gaze data for each segment of interest (>70%) in Task 2 was available for 16 children in the TD group ($M = 96.5$, $SD = 8.3$), 18 children in the DLD group ($M = 93.6$, $SD = 15.2$), and 18 children in the ASD group ($M = 89.4$, $SD = 12.9$). Fig. 6 displays the mean distribution of proportions of fixations to objects and speakers in the segments of interest of the test trial in Task 2.

We fitted fixation duration proportions as predicted values in linear mixed models with by-participant random intercepts and with AOI, segment, and group as predictors. Model comparisons revealed a significant effect of AOI, $\chi^2(3) = 215.09$, $p < 0.001$, but no AOI × Segment interaction, $\chi^2(3) = 3.11$, $p = 0.37$. The absence of an AOI × Segment interaction in Task 2 clearly revealed a different pattern of fixations to speakers' faces and objects from what we observed in Task 1. The allocation of visual attention was not directly influenced by the identity of the speaker in the same way as in Task 1. In Task 2, children paid more attention to the face of the active speaker and to the object she was pointing at even when the active speaker was the less reliable speaker.

We further evaluated whether distribution of gazes across AOIs could be predicted by group. The AOI × Group interaction significantly improved the fit of the model built with only the AOI factor, $\chi^2(6) = 40.98$, $p < 0.001$. No AOI × Segment × Group triple interaction, $\chi^2(11) = 7.74$, $p = 0.73$, was detected. We then conducted post hoc pairwise comparisons of the maximal model (AOI and AOI × Group interaction as fixed effects); the effects of this model are plotted in Fig. 7. Children in the ASD group attended significantly more to the indicated object than children in the TD group ($\beta = 0.15$, $t = 3.80$, $p < 0.001$) and children in the DLD group ($\beta = 0.15$, $t = 3.83$, $p < 0.001$). By contrast, they looked less at the face of the active speaker compared with TD children ($\beta = -0.15$, $t = -3.66$, $p < 0.001$). The same tendency in attending less to the active speaker's face in the ASD group was observed in comparison with the DLD group but failed to reach significance ($\beta = -0.08$, $t = -2.06$, $p = 0.08$). There was no difference between the TD and DLD groups in the amount of fixation on the faces of active speakers ($\beta = -0.05$, $t = -1.66$, $p = 0.21$) or on the objects indicated by them ($\beta = 0.00$, $t = 0.14$, $p = 0.98$). Proportions of fixations toward the speaker who was not acting and the other object did not significantly differ among groups.

Summing up, whereas in Task 1 attention allocation patterns during word mappings performed by two speakers were clearly influenced by the previous accuracy of speakers, no such pattern robustly emerged in Task 2. There was, however, a difference between children with ASD and both the TD and DLD groups regarding fixations to active speakers and to the objects that they indicated. Children in the ASD group were more attracted by objects and less affected by speakers' faces compared with children in the TD and DLD groups in this task. These results are consistent with the results of previous studies that reported diminished attention to social stimuli in ASD. Note, however, that children in all groups were attentive to the demonstration made by both speakers given that they were mostly attracted by the objects indicated by active speakers. Therefore, children in the ASD group did display sensitivity to the cues provided by active speakers given that they followed speakers' pointing in the same way as children in TD and DLD groups.

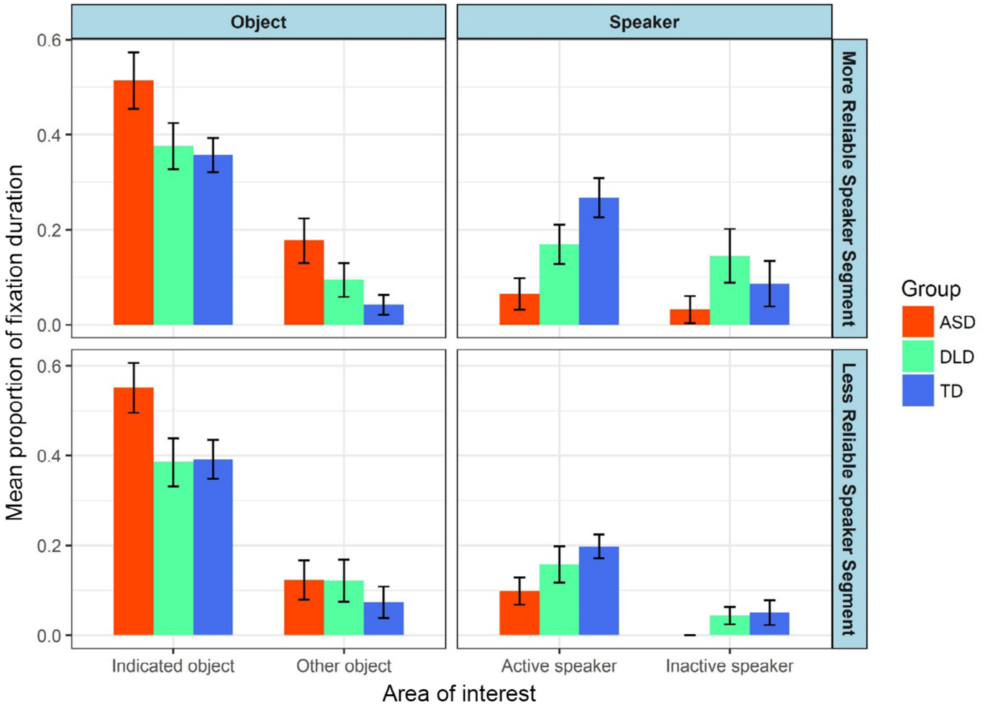

Fig. 6. Task 2: Mean proportions of fixation duration across four areas of interest per segment by group. Error bars display standard errors of the means. ASD, autism spectrum disorder; DLD, developmental language disorder; TD, typically developing.

Discussion

This is the first comparative study of selective social learning in children with and without autism. It is also the first study to explore the dynamics of children's attention allocation to referents and speakers' faces during word–object mapping performed by previously accurate and inaccurate speakers. Several findings are particularly noteworthy and may shed light on the development of selective trust.

In Task 1, children in all groups proved to be sensitive to the contrast between accurate and inaccurate speakers given that they favored the word–object mapping provided by a previously accurate speaker over that made by an inaccurate speaker. Second, not only was speakers' reliability encoded in children's decisions on how to map words onto objects, but also eye-tracking data were distributed according to the speakers' previous accuracy. Moreover, the distribution of children's fixations revealed that prior accuracy of a speaker was already taken into consideration when children observed speakers' mappings and before they made their own referent choice. This distribution was affected by the speakers' identity in a comparable way across the three groups; children focused their attention on the face and the object shown by a reliable speaker when the speaker was giving her or his answer, but they did not follow the answer of a previously inaccurate speaker and explored the second available object during that speaker's demonstration.

Two competing accounts explaining early children's sensitivity to the accuracy of speakers' testimony were evoked in the Introduction. Some scholars argue that early selective learning is built on children's ability to interpret speakers' behaviors as proxies for underlying mental states. Others hold that selective learning relies on a less sophisticated associative mechanism. Under the latter model, children exhibit sensitivity to speakers' accuracy by avoiding informational sources that previously demonstrated unexpected or abnormal behavior. Our eye-tracking data revealed that children in all

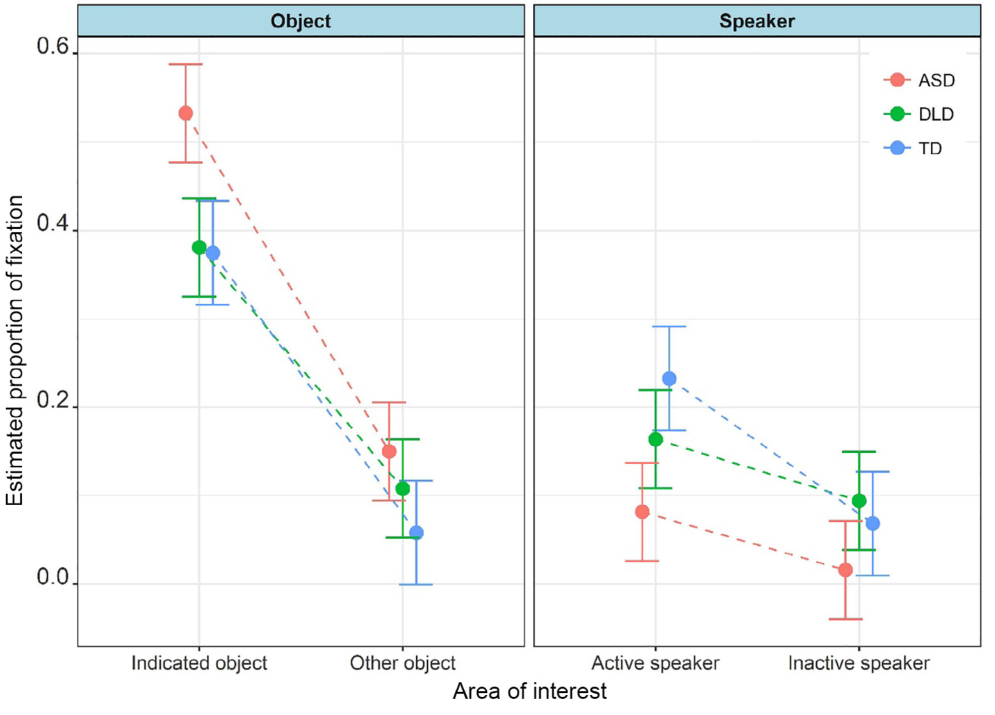

Fig. 7. Estimated proportions of fixation across areas of interest by group in Task 2. Vertical bars correspond to 95% confidence intervals. ASD, autism spectrum disorder; DLD, developmental language disorder; TD, typically developing.

groups tend to pay less attention to word mappings produced by a previously inaccurate speaker—even before children needed to make their own lexical choice. Such a pattern of reduced attention to the cues provided by an inaccurate speaker is consistent with a dichotomous surface trait attribution mechanism (conventional vs. unconventional speaker's behavior).

We also found that this pattern of attention distribution, in Task 1 was shared by children in the ASD, DLD, and TD groups. Moreover, children in all groups displayed the same preference for objects shown by accurate speakers. Recall that sociopragmatic accounts of selective learning would predict that children with ASD should not distinguish between reliable and unreliable information sources owing to impaired mentalizing abilities. Contrary to such a prediction, we found that children with ASD adjusted their attention to social cues in word-learning situations according to speakers' accuracy.

Our results can be interpreted in two different ways. First, one could surmise that children with ASD create epistemic models of speakers and, thus, demonstrate better social understanding than previously thought. However, such an interpretation is not supported by robust empirical evidence that children with ASD fail to track and assess mental states of others. Second, one may argue that our results rather converge with a conservative model of selective learning. According to this line of thought, children do not need to make inferences about speakers' knowledge state in our Task 1 because they can exhibit social selectivity by simply avoiding cues from inaccurate sources that showed very unconventional behavior. There is no reason to believe that such an associative mechanism is not preserved in ASD. On the contrary, even rather young infants on the spectrum are able to detect simple rule-based contingencies (Bhat, Galloway, & Landa, 2010; Klinger & Dawson, 2001) and may encode word–referent pairs by associating word forms with a speaker's gaze cues, as was discussed in the Introduction. Although performance in the task was not predicted by group membership, we found that it correlated with verbal and nonverbal IQ skills, suggesting that such an unsophisticated trait attribution mechanism still requires a certain level of overall general mental functioning.

Thus, we believe that our results are in line with the idea that children may rely on a simple associative process when deciding about the credibility of the informational source in tasks where trust decisions can be based on a simple trait attribution heuristic. Both the performance above chance by all groups of children and the eye-tracking data supported this conclusion. Crucially, we also found that children with ASD could use social cues flexibly by preferring accurate sources of information over inaccurate ones;however, such flexibility is probably underpinned by a rather unsophisticated process of dichotomous trait attribution.

A more complex picture emerges from children's performance in Task 2. Recall that in this task speakers identified familiar objects correctly but differed on how they could achieve their responses; one speaker was consistently assisted by a puppet, whereas the other speaker answered correctly with no help. Some results from this task corroborate the idea that atypically developing children may fail to critically evaluate the competence of speakers given that only TD children were found to perform above chance. However, the group effect disappeared once nonverbal IQ was added as a covariate in the tested GLM of children's choices. Thus, it is possible that TD children's capability of drawing inferences from the speakers' behavior in this task is primarily associated with the fact that TD children outperformed children in the clinical groups on general reasoning skills as measured by nonverbal IQ tests.

Therefore, it is likely that in Task 2 those children who failed to use the information about speakers' reliability did so because of weaker general inference-making abilities. However, given that children in the ASD and DLD groups had lower nonverbal IQs at the group level, the range of scores in the subgroup analyses was restricted, reducing their sensitivity. Some available evidence suggests that TD children as young as 4 years display selective learning in the similar contexts (Einav & Robinson, 2011). A question for further research is whether younger TD children, with nonverbal IQ skills in the same range as those of children with ASD or DLD, would perform at chance in this task and whether nonverbal IQ skills predict selectivity in social learning outcome in a large sample of young TD children.

Interestingly, TD children were found to prefer surface trait cues such as attractiveness (Bascandziev & Harris, 2014), physical force (Fusaro et al., 2011), and in-group membership with a speaker (Elashi & Mills, 2014) over the more relevant information about demonstrated expertise when judging about speakers' reliability. It has been suggested that these difficulties are associated with immature executive functioning skills; children fail to inhibit salient appearance cues and consequently fail to process more relevant information on speakers' situational knowledgeability (Hermes, Behne, Bich, Thielert, & Rakoczy, 2018). Notably, these studies reveal the importance of taking into account children's general cognitive resources in tasks on social trust.

Yet, surprisingly few studies have addressed the question of how individual differences in general reasoning skills may affect children's ability to identify reliable informational sources. It is likely that individual differences in reasoning skills may strongly influence children's epistemic vigilance and should be accounted for along with other factors. Moreover, general reasoning skills may contribute to the development of rational trust beyond mentalizing skills that are usually evoked as predictors of children's selectivity. As we already pointed out above, in complex selective learning tasks children need both to collect the information about reliability from speakers' prior behavior and then apply this information to decide whether utterances by these speakers should be ignored or not. Interestingly, in a study by Mills and Elashi (2014), which explored individual (and not only developmental) differences in the ability to identify distorted claims in a sample of TD children aged 6 to 9 years, mentalizing abilities correlated with the accuracy of children's responses, but only age and general IQ skills were found to uniquely predict children's ability to identify distortion.

Even though our results show that general reasoning abilities play an important role in the development of rational trust, future research will be needed to establish other aspects of cognitive and social development that may explain why children with ASD and children with DLD failed to select more reliable informational sources. This may be achieved by measuring social-pragmatic skills and by increasing the number of testing trials in order to gain in sensitivity and reliability of subsequent analyses.

Nevertheless, two important findings from the eye-tracking dataset in Task 2 are worth emphasizing. First, children did not display the same pattern of avoiding demonstrations provided by less accurate speakers as in Task 1. The fact that eye-tracking data patterns in this task do not depend on speakers' prior behavior in any group suggests that children were not using speakers' models directly while attending to speakers' mappings. This observation supports the idea that a different process may be involved in social selective learning tasks in different contexts. Consequently, although children directly avoid cues offered by speakers who have previously displayed unusual behavior of misidentifying common objects, children's attention does not seem to be directly affected by the more subtle difference in speakers' degree of expertise. This strongly suggests that a more sophisticated process is required to apply the information on speakers' potential credibility during word–object mapping in Task 2.

The second key finding of Task 2 is the increased proportion of attention allocated to objects by children in the ASD group as compared with both the DLD and TD groups. Our analyses of gazes directed to speakers' faces and objects revealed that participants from all three groups preferentially gaze toward the object that was indicated by the active speaker. However, whereas this object captured nearly the entirety of the visual attention span of children with ASD, the attention of children in the TD and DLD groups was also attracted by the face of the active speaker. Although in our task speakers' faces did not contain information that could be used to evaluate reliability, the fact that children in the ASD group were less attracted to faces may still have important implications for the development of selective trust. In many learning contexts, informants' faces enclose cues allowing one to detect deceptive behaviour, to evaluate informants' level of uncertainty, or to recognize ironic statements. If children with ASD do not explore faces for a sufficient amount of time, they may fail to learn to identify these cues. Consequently, they might not be able to use these cues to assess reliability of speakers and accuracy of information that they convey. The question of whether reduced interest to faces affects the ability to trust and distrust selectively in ASD is another topic that clearly merits further investigation. In addition, future studies may address the question of whether diminished attention to speakers' faces in similar tasks is associated with the severity of autistic symptoms.

Our results demonstrate that children with ASD can use speakers' prior accuracy in tasks on social selective learning. We have argued that these findings support the following theoretical conclusions. First, children may learn selectively using a simple associative heuristic rather than a sophisticated inference-based mechanism; they directly avoid information provided by previously inaccurate speakers, as demonstrated by the eye-tracking data collected during speakers' demonstration of mappings for novel words. This pattern of attention allocation was the same across all three groups of children (with ASD, with DLD, and TD). Next, explicit responses indicated that children in the ASD, DLD, and TD groups displayed a strong preference for the mappings provided by the previously accurate speaker. Finally, a pattern of attention allocation associated with speakers' previous accuracy was not detected in a learning situation where both speakers provided accurate mappings for familiar labels but differed on how they could achieve such accuracy. Children in the two clinical groups, but not in the TD group, performed at chance in this latter task; however, nonverbal IQ score also predicted mapping choices of all tested children. Because children with ASD and children with DLD had lower nonverbal IQs compared with the TD group, it is hard to determine whether children's performance in this task is uniquely associated with general causal inferencing abilities or whether it is also associated with other group-related factors such as mentalizing abilities.

The eye-tracking method used in this study, with its emphasis on exploring children's processing of testimony, may be fruitfully applied to further investigation of how children process online information provided by speakers with different degrees of credibility in tasks on selective trust. Finally, beyond its theoretical value, research on the development of mechanisms supporting the ability to endorse reliable informational sources and to ignore unreliable ones has important practical implications. Our society is increasingly overloaded with information, and it is crucial to ensure that children with and without ASD develop epistemic vigilance. Our research suggests that both general reasoning abilities and attention to social cues may influence development of rational trust in children with ASD and, thus, could become a potential focus for future educational intervention.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2019.104697.

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