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Social perception in children and adolescents with ADHD: The role of higher-order cognitive skills

Ramona Cardillo [1,4], Giulia Crisci [*,2,4], Stefano Seregni, Irene C. Mammarella [*,3]

Department of Developmental and Social Psychology, University of Padova, Via Venezia 8, 35131 Padova, Italy

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ABSTRACT

Despite children with ADHD frequently experiencing difficulties in social perception, the mechanisms underlying this impairment have been poorly explored. In this study, we examined social perception in children with ADHD, comparing them with typically-developing (TD) children on semi-naturalistic tasks, and considering the effect of nonverbal signal recognition. Our aim was to ascertain whether the two groups' social perception related to different types of stimulus (video, audio or combined/multimodal). The role of three higher-order cognitive skills (theory of mind, attention and pragmatic language) was also investigated. Thirty-six children with ADHD, and 36 TD controls were tested. Social perception was significantly associated with participants' ability to recognize nonverbal signals, and with the stimulus presentation modality. Children with ADHD only performed less well than TD children with combined stimuli. As concerns the higher-order cognitive skills, theory of mind had a significant role in both groups, but only with the video and combined stimuli, while attention explained most of the variance in social perception for all types of stimulus. Better pragmatic language skills were only associated with a better social perception in TD children, whatever the type of stimulus presented. Semi-naturalistic tasks should be included when assessing social perception in ADHD, and both theory of mind and attention should be the object of efforts to enhance social perception in the ADHD population.

Attention-deficit/hyperactivity disorder (ADHD) is a neurodevelopmental condition characterized by inattention, impulsivity, and hyperactivity (Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition [DSM 5], American Psychiatric Association [APA], 2013). Children and adolescents with ADHD are approximately four times more likely to experience difficulties in their social interactions with peers than children without the condition (Imanipour et al., 2021), showing impairments in the social domain as well as in the cognitive and behavioral domains (Hoza et al., 2010; McQuade et al., 2017; Staikova et al., 2013; pp. 2, 1208). Within the social domain, one influential component is social perception, a set of skills that enable individuals to represent and interpret social cues, and understand social interactions (Uekermann et al., 2010). Social perception includes the recognition of emotions and nonverbal signals, which enables us to interpret social signals conveyed by eye contact, facial expressions, gestures, posture, distance between people, voice, prosody, and touch (Semrud-Clikeman, 2010).

* Corresponding authors.
E-mail addresses: criscigiulia@gmail.com (G. Crisci), irene.mammarella@unipd.it (I.C. Mammarella).
[1] https://orcid.org/0000–0001-6891–0690
[2] https://orcid.org/0000–0002-6629–9389
[3] https://orcid.org/0000–0002-6986–4793
[4] RC and GC contributed equally to this work.

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Some previous studies trying to shed light on social difficulties associated with ADHD identified impairments in social perception (Bora & Pantelis, 2016; Semrud-Clikeman et al., 2010; Uekermann et al., 2010). Findings have been mixed, however (Wells et al., 2019), and some questions remain. For a start, it is not clear whether these difficulties relate to the type of task presented or represent a stable impairment (Wells et al., 2019). Second, previous research pointed to the need to investigate the processes underlying social perception to clarify why children with ADHD have difficulties (Imanipour et al., 2021), but few studies have done so. Focusing on social perception and its possible underlying cognitive mechanisms therefore remains a priority to shed more light on the impaired social interaction of children with ADHD.

1. Social perception in ADHD

Recent research has suggested a link between ADHD and social perception impairments related to the recognition of emotions and nonverbal signal (Bora & Pantelis, 2016; Uekermann et al., 2010). Several studies found, for instance, that children with ADHD performed less well than their typically-developing (TD) peers when asked to label emotions in facial expressions or to match facial expressions with their own emotions (Tehrani-Doost et al., 2017). Findings have not always been consistent, however. For example, when Wells et al. (2019) used a series of four counterbalanced tasks to systematically manipulate the emotional content and working memory demands, they obtained significant evidence against any emotion recognition deficit in children with ADHD. They suggested that between-group differences identified in previous studies related to the types of measure used, and to the demands of the tasks involved. It is worth noting that most previous studies investigated social perception by focusing primarily on children's ability to identify emotional states accurately when presented with facial expressions (often static pictures) or vocal expressions in isolation (see Bora & Pantelis, 2016 for a review), mainly using matching tasks. In real-life social situations, emotions are conveyed by combinations of dynamic facial, vocal, and bodily expressions, and contextual information is believed to play a significant part in how emotions and nonverbal cues are interpreted (Magill-Evans et al., 1995). The multifaceted complexity of social perception therefore could not be captured by the previously-used emotion recognition tasks, in which little attention had been paid to the role of such crucial additional factors (nonverbal signals recognizable in ambiguous situations, or emotional information that might be inferred from a given context, and so on).

To the best of our knowledge, only three studies to date have examined social perception abilities in a semi-naturalistic context, taking both emotion recognition and nonverbal signal recognition into account. These studies used the Children and Adolescents Social Perception (CASP) measure, in which video recordings of social interactions between two or more child actors were shown with voice prosody intact, but lexical content obscured by distortion. Using this task, Fine et al. (2008) found that ADHD children performed less well than controls on social perception. Semrud-Clikeman (2010; Semrud-Clikeman et al., 2010), in two different studies, analyzed social perception abilities of children with different ADHD subtypes (combined or predominantly inattentive) comparing them with controls (Semrud-Clickeman, 2010) or with children presenting other neurodevelopmental conditions (Semurd-Clikeman et al., 2010). Results of both studies showed that the difficulties of children with ADHD did not differ by subtype of ADHD (combined or predominantly inattentive); they all performed significantly worse than controls when interpreting emotional and nonverbal signals. The results of these studies support the conviction that children and adolescents with ADHD have significant social perception impairments when tested in a semi-naturalistic context, whatever the characteristics of the task administered.

While these results are interesting, whether the impairment is affected by the type of (visual or oral) stimulus presented remains to be seen. Studies on typical populations of young or older adults (Cortes et al., 2021; Hunter et al., 2010; Wieck & Kunzmann, 2017) identified differences in participants' performance depending on the type of stimulus presented. Hunter et al. (2010) presented three different types: two series of 10 dynamic faces portraying four different emotions (i.e., video stimuli); the corresponding prosodic emotional stimuli for emotions (i.e., audio stimuli); and both together (i.e., combined/multimodal stimuli). Comparing the three conditions (i.e., video, audio and combined/multimodal), the Authors found that participants of all ages could benefit from a multimodal presentation and performed less well when video or audio stimuli were presented alone. Similarly, Cortes et al. (2021), and Wieck and Kunzmann (2017) reported that emotion recognition impairments became less evident when dynamic emotional stimuli were presented in a combined/multimodal condition.

Taken together, previous studies have identified social perception impairments in children with ADHD, but whether these difficulties relate to the type of task administered is still unclear. Semi-naturalistic tasks, in which different stimuli presentation modalities are manipulated, appear to be particularly suitable for shedding light on this complex domain, and revealing possible differences between children with ADHD and their TD peers.

1.1. *Higher-order cognitive skills and social perception*

Given the complex nature of social perception, some studies have recommended investigating the role of various higher-order cognitive skills underlying it in order to examine the possible contribution of different abilities to social perception difficulties experienced by children with ADHD (Imanipour et al., 2021). To be more specific, theory of mind (ToM), attention and executive functions, and pragmatic language skills appear to be fundamentally important in this complex domain (Beauchamp & Anderson, 2010).

ToM represents the ability to attribute mental states (beliefs, intentions, desires, pretending, knowledge) to ourselves and others, and to understand that others' mental states may differ from ours (Frith & Frith, 2006). ToM is essential to humans' social interaction (Frith & Frith, 2003; Milligan et al., 2007), and has been found significantly impaired in individuals with ADHD (see Bora & Pantelis, 2016 for a review). A close relationship between ToM and social perception was recently demonstrated in a biopsychosocial and neuroscientific theoretical model (Beauchamp & Anderson, 2010; Yang et al., 2015). That said, the little evidence obtained so far does not seem to identify significant correlations between ToM and social perception in children with ADHD, unlike the case of TD controls (Charman et al., 2001).

Other processes underlying social perception concern attentional control (i.e., selective attention and sustained attention, self-regulation, response inhibition), cognitive flexibility (i.e., working memory, attention shifting), and goal setting (i.e., initiating, planning, problem solving), which all come under the umbrella term of executive functions. Although the neuropsychological profile of individuals with ADHD varies, a huge number of studies identified executive function impairments associated with this condition (see Sergeant et al., 2002 for a review). Difficulties affecting executive functions, especially attention, can affect the ability of children with ADHD to process social information (Semrud-Clikeman et al., 2010), and symptoms of inattention have been found being associated with poor social perception (Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010).

Communication is another domain strongly associated with social perception (Bruce et al., 2006). Expressive and receptive language skills are clearly needed for social interactions, influencing how messages exchanged between individuals are expressed and understood. Subtle language processing abilities are also essential (Beauchamp & Anderson, 2010). Pragmatic language skills are needed to use language effectively (Cardillo et al., 2021), conveying meaning beyond the words used and without ambiguity. Impairments in this domain are strongly related to social perception ability (Adams, 2002). Previous studies (Leonard et al., 2011; Staikova et al., 2013; pp. 2, 1208) found pragmatic language skills impaired in children with ADHD, especially as regards prosody, turn taking, and drawing inferences. These deficits affected academic functioning (Troia, 2011), peer relationships (Leonard et al., 2011), and general adjustment (Landa, 2005) in children and adolescents with a clinical diagnosis of ADHD.

To sum up, children and adolescents with ADHD have revealed difficulties in at least three higher-order cognitive domains, such as ToM, attention and executive functions, and pragmatic language, which have been found closely related to social perception (Bora & Pantelis, 2016; Borella et al., 2013; pp. 2, 1208; Charman et al., 2001; Crisci et al., 2021; Semrud-Clikeman et al., 2010; Staikova et al., 2013), but – surprisingly – no studies have examined all these domains together to better explain the social perception difficulties associated with ADHD.

1.2. *The present study*

As outlined above, previous research has generated mixed findings on social perception in children and adolescents with ADHD (Fine et al., 2008; Semrud-Clikeman et al., 2010; Uekermann et al., 2010; Wells et al., 2019). Few studies analyzed social perception abilities in a semi-naturalistic context (Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010), and none used different types of social stimulus (i.e., video, audio, and combined/multimodal). While social perception difficulties have been described in children and adolescents with ADHD (Bora & Pantelis, 2016; Charman et al., 2001; Staikova et al., 2013; pp. 2, 1208), the roles of ToM, attention and inhibition, and pragmatic language – all domains closely related to social perception abilities (Beauchamp & Anderson, 2010; Bruce et al., 2006; Fine et al., 2008; Yang et al., 2015; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010) - have yet to be investigated together.

The first aim of the present study was therefore to examine social perception in children and adolescents with ADHD, comparing them with TD individuals, and considering the effect of nonverbal signal recognition. We also investigated whether the two groups' social perception was differently related to the type of social stimulus presented (i.e., video, audio or combined/multimodal). Our second aim was thus to analyze the different contributions of the higher-order cognitive skills needed for each type of social stimulus (i.e., video, audio and combined/multimodal). The role of ToM, attention and inhibition, and pragmatic language skills was considered in the two groups. We administered: verbal and figurative stimuli to assess ToM; a measure of participants' ability to pay attention and inhibit automated responses to assess their attention and executive functioning problems; and a measure of pragmatic language to test their ability to infer information not explicitly stated, and their communication skills.

In the light of previous studies on social perception in children with ADHD (Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010), we expected our sample of children and adolescents with ADHD to perform less well than TD children with video and combined social stimuli because of their resemblance to real-life interactions, whereas audio stimuli might be easier to interpret because of their lower processing complexity (Fuermaier et al., 2018; Huizenga et al., 2009; Plummer & Eskes, 2015). We also expected a significant positive association between nonverbal signal recognition and social perception in both groups, consistently with previous research (Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010). Moreover, TD participants were expected to benefit from the presentation of multimodal stimuli, and to perform less well with the unimodal ones, as already seen in young and older adults (Cortes et al., 2021; Hunter et al., 2010; Wieck & Kunzmann, 2017).

Regarding the underlying role of higher-order cognitive skills (i.e., ToM, attention, inhibition and pragmatic language), we expected them to be related to social perception, in agreement with previous theoretical models (Beauchamp & Anderson, 2010; Yang et al., 2015), and evidence from research (Imanipour et al., 2021; Leonard et al., 2011; Semrud-Clikeman et al., 2010). No previous studies examining the role of higher-order cognitive domains took the type of social stimulus (i.e., video, audio, and combined/multimodal) into account, but we expected to see a different involvement of each higher-order skill, depending on the type of stimulus presented. Specifically, ToM could be important with video and combined stimuli because facial recognition and eye gaze detection are needed to decode them (Mitchell & Phillips, 2015). We also expected a negative association between social perception and inattention symptoms, and a less robust relation with inhibition problems for all types of social stimulus, in agreement with Semrud-Clikeman (2010); Semrud-Clikeman et al. (2010). Finally, pragmatic language might be related to all three types of stimulus, particularly video or audio stimuli, when certain relevant information (lexical content or facial expressions, respectively) are not intelligible (Russell, 2007; Socher et al., 2019).

2. Method

2.1. Participants

Seventy-two children (66 males) between 8 and 15 years of age (in months M=128.75, SD=18.01) were included in the study. The sample was divided into two groups: 36 children had a clinical diagnosis of ADHD (33 males; age range from 95 to 170 months); and 36 were TD children (33 males; age range from 88 to 174 months). The two groups were matched on sex, chronological age [$F(1, 70) = .02$, $p = .90$, *Adjusted* $R^2 = .01$], and an intelligence quotient (IQ) [$F(1, 70) = 3.40$, $p = .07$, *Adjusted* $R^2 = .03$], as measured using the WISC-IV (Wechsler, 2011).

Children with ADHD were enrolled at centers specializing in neurodevelopmental disorders, hospitals, or clinics. Children with ADHD had a clinical diagnosis meeting the DSM 5 criteria (APA, 2013), previously established by expert practitioners (child psychiatrists or psychologists). The inclusion criteria for the present study demanded that children's diagnoses be confirmed by T scores of 65 or higher for inattention and/or hyperactivity on Conners' Parent Rating Scale (CPRS-R:S, Conners, 1997) as well as meeting the DSM 5 (APA, 2013) criteria. The ADHD group scored significantly higher than the TD group on all Conners' indexes: oppositional [$F(1, 70) = 27.11$, $p < .001$, *Adjusted* $R^2 = .27$]; cognitive problems/inattention [$F(1, 70) = 80.99$, $p < .001$, *Adjusted* $R^2 = .53$]; hyperactivity [$F(1, 70) = 88.69$, $p < .001$, *Adjusted* $R^2 = .55$]; and ADHD index [$F(1, 70) = 138.1$, $p < .001$, *Adjusted* $R^2 = .66$]. The TD children were recruited through contacts in the local community or at local schools in Italy. All participants were native Italian speakers, and none had visual or hearing impairments or any diagnosed neurological conditions. For all participants, the exclusion criteria were: a concurrent diagnosis of other neurodevelopmental disorders; a history of neurological problems; ongoing use of medication affecting the central nervous system; or an IQ below 85. The participants' characteristics are summarized in Table 1.

3. Materials

3.1. Social perception

3.1.1. Child and Adolescent Social Perception Measure

Three modified versions of the Child and Adolescent Social Perception Measure (CASP, Magill-Evans et al., 1995) were developed for the present study. Like the original, the first version includes 10 videos (each lasting approximately 40 s) in which voice prosody could be heard, but the lexical content of the dialogue was obscured by distortion (video condition); the second includes 10 audio recordings in which both prosody and lexical content could be heard (audio condition); the third includes 10 videos of children interacting, in which the audio (prosody and lexical content) was intelligible (combined condition). For all three types of stimulus (video, audio and combined), the characters' emotions were the same in each story; only the context changed. The stories were presented in a counterbalanced order. After each story had been presented, the child was asked - using an open question format - to say what each of the characters was feeling (social perception - SP score). One point was awarded for each emotion correctly attributed, for a maximum of 46 points for each type of stimulus. The children were then asked to explain how they could tell what the characters felt. Common examples of their responses include: "from the smile" or "the voice went up". This type of answer scored 1 point if it indicated the correct identification of a nonverbal cue, or 0 if the child mentioned other contextual aspects not directly related to the characters' emotions (nonverbal signals score). The scoring procedure considered accuracy for both the SP score and the nonverbal signals score. Cronbach's alpha was.88 for the total SP score, and.92 for the nonverbal signals score (Magill-Evans et al., 1995).

4. Higher-order cognitive skills

4.1. Theory of mind task

The ToM task from Nepsy II (Korkman et al., 2007) was used to measure participants' ability to attribute emotions, desires, beliefs, and knowledge to others. This task includes two conditions: verbal and contextual. The *verbal ToM task* consists of 15 items. It is mainly

Table 1
Characteristics of the ADHD and typically-developing (TD) groups: means (M), standard deviations (SD) and results of ANOVAs.

	ADHD (n = 36)	TD (n = 36)	ANOVAs		
	M (SD)	*M (SD)*	*F (1, 70)*	*p*	*Adjusted R^2*
Age (in months)	129.03 (17.73)	128.47 (18.54)	.02	.90	.01
IQ	108.42 (9.45)	112.17 (7.74)	3.40	.07	.03
CPRS-R:S					
Oppositional	60.17 (12.65)	46.50 (9.39)	27.11	< .001	.27
Cognitive problems, Inattention	70.58 (6.00)	49.28 (12.88)	80.99	< .001	.53
Hyperactivity	66.42 (12.13)	44.00 (7.53)	88.69	< .001	.55
ADHD	72.03 (6.54)	48.61 (10.01)	138.10	< .001	.66

Note. ADHD= group with attention deficit/hyperactivity disorder; TD= typically-developing group; IQ= intelligence quotient; CPRS-R:S=Conners' Parent Rating Scales-Revised: Short form.

a measure of the ability to understand beliefs, intentions, thoughts, and feelings, considering another individual's point of view. All questions are based on verbal scenarios with or without pictorial support. The *contextual ToM task* includes 8 items, and measures the respondent's ability to relate emotions to social contexts. Pictures of children in several social contexts are shown, in which there is a target girl whose face is hidden. The respondent is asked to infer the girl's emotion based on the context and situation, and to select one of four photographs of the girl's face (showing different emotions) to indicate the appropriate emotion. The raw scores (maximum raw score for verbal ToM task = 17 points; for contextual ToM task = 8 points) were compared with normative data, and z scores were computed. Test-retest reliability ranges between $r = .70$ to $r = .77$ (Brooks et al., 2009).

4.2. Continuous Performance Task

The Continuous Performance Task (CPT), adapted from Conners' Continuous Performance Task-2 (CPT-2, Conners, 2000), is a neuropsychological test for assessing attention problems and the ability to inhibit automated responses. The test was administered using a laptop computer with a 15-inch LCD screen, programmed with OpenSesame software (Mathôt et al., 2012). There were 360 stimuli (different letters), presented one at a time in the center of the computer screen with various interstimulus intervals (1, 2 or 4 s). The interstimulus interval was counterbalanced within the test. The task lasted about 14 min. The children were instructed to press the spacebar when each letter appeared on the screen, but not if it was the letter "X" (which appeared at random 10% of the time). Two variables were considered: (a) the proportion of errors of omission (i.e. failure to respond to a target letter), representing a measure of attentional difficulties; and (b) the proportion of errors of commission (i.e. failure to inhibit a response when the letter "X" appears), representing a measure of inhibition difficulties. Cronbach's alpha was.80 (Shaked et al., 2020).

4.3. Pragmatic language

The pragmatic language task, adapted from Cardillo et al. (2021), is a paper-and-pencil task assessing pragmatic language, and the ability to infer information not explicitly stated. It consists of two different subtests covering verbal and pictorial inferences, each comprising 20 items. For the *verbal inferences*, participants were asked to listen to short stories, while for the *pictorial inferences,* they were instructed to look at figures depicting social scenes. Then they answered questions about information that had not been explicitly presented but could be gleaned from contextual cues or previous knowledge. Participants scored 1 point for each correct answer (maximum raw score = 20 points in each subtest, verbal and pictorial). Cronbach's alpha was.86 (Cardillo et al., 2021).

5. Procedure

The study was approved by the Ethics Committee of the University of Padua. Written consent was obtained from children's parents before they took part in the study. Participants were tested in a quiet room during two individual sessions lasting approximately 40 min each. Tasks were administered in a counterbalanced order. Instructions were given for each task, and participants practiced with each task before starting the experiment. For the computer-based task, the children sat in front of the computer screen and the experimenter sat at the child's side to present the task.

5.1. Data analyses

Statistical analyses were run in two stages, using R (R Core Team, 2015). First, the SP accuracy data obtained from the CASP were analyzed using a mixed-effects logistic model (Baayen et al., 2008), and the 'lme4′ package (Bates et al., 2015). The fixed effects were group (ADHD and TD), nonverbal signals score, and the CASP social stimuli (i.e., video, audio or combined social stimuli), while participants were treated as random effects. Then separate linear regressions were run for each type of social stimulus (video, audio or combined) to investigate the association between the dependent variable (SP) and different independent variables: group (ADHD or TD), verbal ToM, contextual ToM, errors of omission and commission from the CPT, and verbal and pictorial inferences from the pragmatic language task. The main effects, and the interaction between group and each of the other independent variables were tested for the three CASP conditions (with video, audio and combined social stimuli).

The significance of fixed effects (in the first stage), and main effects (in the second stage), and their interactions were examined using likelihood ratio tests for nested models. The Akaike information criterion (*AIC*; Akaike, 1974) was also recorded for each model, a lower *AIC* providing a better description of the relationships between variables (Bentler, 1990; Schermelleh-Engel et al., 2003). Graphical effects were obtained using the "effects" package (Fox, 2003).

6. Results

6.1. Social perception accuracy

No main effect of group emerged ($\chi 2(1) = 1.60$, $p = .21$, full model: $AIC = 11603$, model without group: $AIC = 11603$). The main effect of the type of social stimulus was significant ($\chi 2(2) = 120.71$, $p < .001$, model without the type of social stimulus: $AIC = 11720$), showing a better performance for audio than for combined ($p = .006$) or video ($p < .001$) social stimuli. SP accuracy with the combined stimuli was significantly greater than with the video stimuli ($p < .001$). The main effect of nonverbal signal scores was significant ($\chi 2(1) = 33.63$, $p < .001$, model without nonverbal signal scores: $AIC = 11635$), higher nonverbal signal scores being associated with greater SP accuracy. No significant interactions emerged between group and nonverbal signal scores ($\chi 2(1) = .62$, $p = .43$, model with the interaction: $AIC = 11605$), or between type of social stimulus and nonverbal signal scores ($\chi 2(2) = 1.30$, $p = .52$, model with the interaction: $AIC = 11606$), while significant interactions emerged between group and type of social stimulus ($\chi 2(2) = 4.68$, $p = .05$, model with the interaction: $AIC = 11503$) (see Fig. 1). Multiple comparisons revealed statistically significant differences between groups for the combined stimuli, with the TD group performing better than the ADHD group ($p = .05$). No significant differences emerged between the groups for the other types of social stimulus. Looking at within-group differences, the TD group performed significantly better with the audio and combined stimuli than with the videos ($p_s <.001$). In the ADHD group there were significant differences between the types of social stimulus ($p_s <.001$), the children performing best with the audio stimuli, and better with the combined stimuli than with the videos. See Table 2 for a summary of all the statistical information emerging from the models.

6.2. Regression analyses

As concerns SP when videos were used as social stimuli, our variables explained 26% of the variance [$F(7, 64) = 5.86$, $p < .001$, full model $AIC = 185.66$]. There were significant associations with the contextual ToM task [$F(1, 65) = 4.56$, $p = .04$, model without the contextual ToM task $AIC = 188.62$], and with CPT omission errors [$F(1, 65) = 13.27$, $p < .001$, model without CPT omission errors $AIC = 197.23$]. The association was positive for the contextual ToM task, and negative for the CPT omission errors, suggesting that participants with stronger contextual ToM abilities and fewer attention problems were better at recognizing emotions from video stimuli. A significant interaction emerged between group and verbal inferences [$F(1, 64) = 8.27$, $p = .005$, model with the interaction $AIC = 178.78$], SP performance being associated with the verbal inferences task, but only for the TD group (Fig. 2A). See Table 3 for a summary of all the statistical information emerging from the models.

Our variables explained 17% of the variance regarding SP from audio stimuli [$F(7, 64) = 3.52$, $p = .003$, full model $AIC = 197.85$],

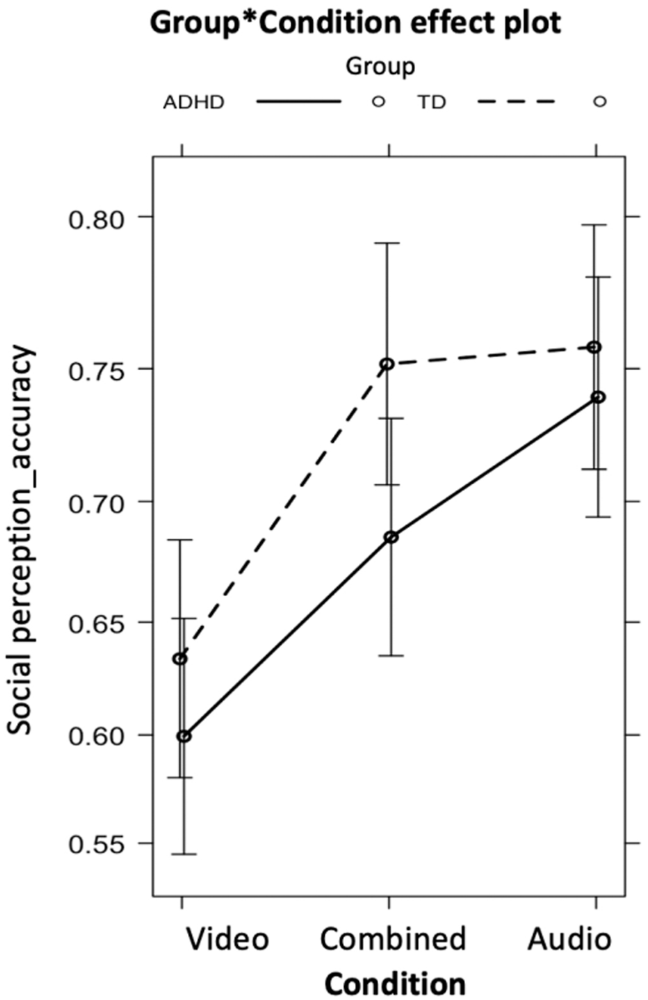

Fig. 1. Interaction between group (ADHD and TD) and type of social stimulus for social perception accuracy in the CASP. Error bars represent 95% confidence intervals. *Note.* ADHD= attention deficit/hyperactivity disorder group; TD= typically-developing group.

Table 2
Results of the mixed-effects logistic model for social perception (SP) accuracy with group (ADHD or TD), type of social stimulus used in the CASP (i.e., video, audio or combined), and nonverbal signals score as fixed effects, and participants as random effects.

	Effects	*gdl*	*χ2*	*p*	*AIC*
SP accuracy	Group (ADHD vs TD)	1	1.60	.21	11603
	Social stimuli	**2**	**120.71**	**< .001**	**11720**
	Nonverbal signal	**1**	**33.63**	**< .001**	**11635**
	Group*social stimuli	**2**	**4.68**	**.05**	**11503**
	Group*nonverbal signal	1	.62	.43	11605
	Social stimuli*nonverbal signal	2	1.30	.52	11606

Note. SP = social perception

which was significantly associated with CPT omission errors [$F(1, 65)$ =10.99, p=.002, model without CPT omission errors *AIC* = 207.26]. This association was negative, suggesting that participants with fewer attention problems performed better in terms of SP from audio stimuli. A significant interaction emerged between group and verbal inferences [$F(1, 64)$ = 7.12, p=.01, model with the interaction *AIC* = 192.14], performance in SP being associated with the verbal inferences task, but only for the TD group (Fig. 2B). See Table 3 for a summary of all the statistical information emerging from the models.

When SP was examined using combined stimuli, our variables explained 40% of the variance [$F(7, 64)$ = 7.77, p<.001, full model *AIC* = 177.03]. There was a significant association with the contextual ToM task [$F(1, 65)$ = 4.86, p=.03, model without the contextual ToM task *AIC* = 180.29], and with CPT omission errors [$F(1, 65)$ = 23.52, p<.001, model without CPT omission errors *AIC* = 197.56]. The association was positive for the contextual ToM task, and negative for the CPT omission errors, suggesting that participants with stronger contextual ToM abilities and fewer attention problems performed better in terms of SP with combined stimuli. A significant interaction emerged between group and verbal inferences [$F(1, 64)$ = 4.04, p=.05, model with interaction *AIC* = 174.55], performance in SP being associated with the verbal inferences task, but only for the TD group (Fig. 2C). See Table 3 for a summary of all the statistical information emerging from the models.

7. Discussion

As mentioned previously, very few studies on ADHD have examined social perception using semi-naturalistic tasks (Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010), also taking the type of stimulus presented (i.e., video, audio or combined/multimodal) into account. The role of ToM, attention and inhibition, and pragmatic language skills in the development of social perception skills has also been under-investigated in children and adolescents with ADHD.

Hence the present study investigates: a) social perception in a semi-naturalistic task, in groups of children and adolescents with ADHD and TD controls, taking nonverbal signal recognition and different types of social stimulus into account; and b) the role of ToM, attention and inhibition, and pragmatic language skills in association with social perception abilities, distinguishing between social stimuli presented in a video, audio or combined format.

Regarding our first aim, we found higher nonverbal signal scores associated with a more accurate social perception in both our groups (ADHD and TD). This finding confirms that nonverbal signal recognition is significantly associated with social perception (Fine et al., 2008; Semrud-Clikeman, 2010), in children with or without any clinical diagnosis of ADHD. Interestingly, social perception accuracy differed between the ADHD and TD groups depending on the type of stimulus presented: children with ADHD fared significantly worse with combined (video and audio) stimuli, but not with audio or video stimuli alone. It is worth noting that the combined stimuli more closely resembled real-life interactions than the audio or video stimuli alone. Our results thus seem to confirm that ADHD is associated with social perception impairments in everyday life interactions (Bora & Pantelis, 2016; Uekermann et al., 2010). That said, these impairments seem to be associated with the number of stimuli to process. Several previous studies found that, for ADHD populations especially, having to divide their attention between different stimuli, or deal with a more complex task could prompt a decline in performance compared with when social stimuli are presented alone (Fuermaier et al., 2018; Huizenga et al., 2009). Our two groups also showed within-group differences relating to which type of social stimulus was presented. The TD children and adolescents performed better with the combined or audio stimuli than with the videos. This result is partially consistent with a report from Hunter et al. (2010), who found that typical young and older adults benefited from multimodal rather than unimodal social stimuli, whatever their age, probably because they more closely resembled real everyday life interactions. Our TD group also fared better with the audio stimuli than with the videos, however (and just as well with the audio as with the combined stimuli). A possible explanation for this result might lie in that children have more limited attentional resources than adults (Cowan et al., 2006), and an audio presentation alone may have enabled our young participants to focus on fewer details, making them easier to understand (Plummer & Eskes, 2015). Our children and adolescents with ADHD also performed significantly better with the audio alone than with the video or combined stimuli, supporting the idea that children with attention problems would also find audio presentations easier to manage. As already reported elsewhere, having to divide their attention between several stimuli affected the ADHD group's performance in several tasks (Fuermaier et al., 2018; Huizenga et al., 2009).

Regarding our second aim, when separate linear regressions were run for each type of social stimulus (i.e., video, audio or combined), our overall results showed a specific contribution of ToM for the video and combined stimuli, and attention - not inhibition - had a primary role for all three types of stimulus. The significant interaction emerging between pragmatic language and group suggests that communication skills were differently involved in the ADHD and TD groups' social perception abilities. As hypothesized, ToM

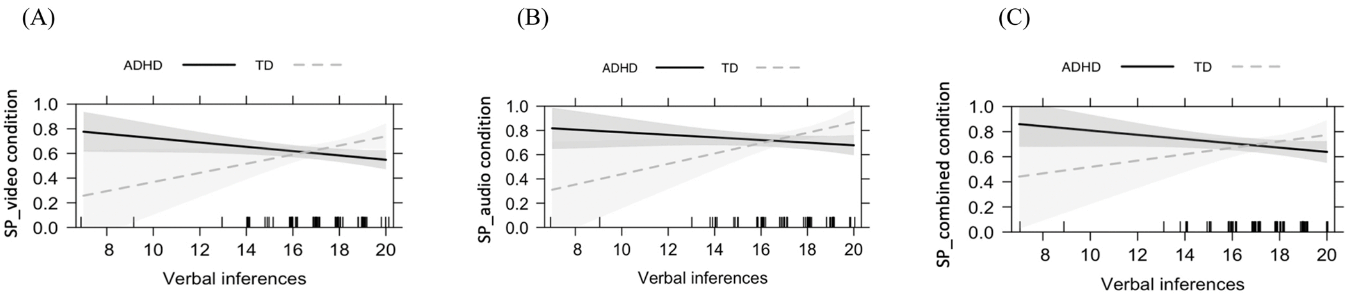

Fig. 2. Interaction between group (ADHD and TD) and verbal inferences - respectively for: (A) video, (B) audio, and (C) combined type of social stimulus - for social perception (SP) accuracy in the CASP. *Note*. ADHD= attention deficit/hyperactivity disorder group; TD= typically-developing group; SP=social perception.

Table 3
Results of the linear models for each type of social stimulus (video, audio and combined) in the CASP with group, verbal ToM, contextual ToM, omission and commission errors from the CPT, and verbal and pictorial inferences from the pragmatic language task as independent variables.

Social stimuli	*Effects*	*F*	*df*	*p*	ΔR^2	*AIC*
Video	Group (ADHD vs TD)	.19	1, 65	.66	.003	183.88
	Verbal ToM task	.01	1, 65	.93	.001	183.67
	Contextual ToM task	**4.56**	**1, 65**	**.04**	**.07**	**188.62**
	CPT omission errors	**13.27**	**1, 65**	**< .001**	**.17**	**197.23**
	CPT commission errors	.05	1, 65	.82	.001	183.72
	Verbal inferences	1.27	1, 65	.26	.01	185.07
	Pictorial inferences	.20	1, 65	.65	.003	183.89
	Group*Verbal ToM task	1.59	1, 64	.21	.02	185.87
	Group*Contextual ToM task	.43	1, 64	.51	.006	187.17
	Group*CPT omission errors	1.13	1, 64	.29	.02	186.39
	Group*CPT commission errors	1.23	1, 64	.27	.02	186.28
	Group*Verbal inferences	**8.27**	**1, 64**	**.005**	**.12**	**178.78**
	Group*Pictorial inferences	.02	1, 64	.89	.001	187.64
Audio	Group (ADHD vs TD)	.22	1, 65	.64	.003	196.10
	Verbal ToM task	.13	1, 65	.72	.002	195.99
	Contextual ToM task	.42	1, 65	.52	.007	196.32
	CPT omission errors	**10.99**	**1, 65**	**.002**	**.15**	**207.26**
	CPT commission errors	.22	1, 65	.64	.003	196.09
	Verbal inferences	.10	1, 65	.76	.001	195.96
	Pictorial inferences	.29	1, 65	.59	.005	196.18
	Group*Verbal ToM task	.38	1, 64	.54	.006	199.42
	Group*Contextual ToM task	.31	1, 64	.58	.005	199.50
	Group*CPT omission errors	.29	1, 64	.59	.005	199.52
	Group*CPT commission errors	2.10	1, 64	.15	.03	197.50
	Group*Verbal inferences	**7.12**	**1, 64**	**.01**	**.10**	**192.14**
	Group*Pictorial inferences	.51	1, 64	.48	.008	199.27
Combined	Group (ADHD vs TD)	.001	1, 65	.99	.001	175.03
	Verbal ToM task	2.12	1, 65	.15	.03	177.37
	Contextual ToM task	**4.86**	**1, 65**	**.03**	**.07**	**180.29**
	CPT omission errors	**23.52**	**1, 65**	**< .001**	**.27**	**197.56**
	CPT commission errors	.69	1, 65	.41	.006	175.80
	Verbal inferences	1.42	1, 65	.24	.02	176.60
	Pictorial inferences	.001	1, 65	.99	.001	175.03
	Group*Verbal ToM task	2.53	1, 64	.12	.04	176.19
	Group*Contextual ToM task	.88	1, 64	.35	.01	178.03
	Group*CPT omission errors	1.13	1, 64	.29	.02	177.75
	Group*CPT commission errors	.87	1, 64	.35	.01	178.03
	Group*Verbal inferences	**4.04**	**1, 64**	**.05**	**.06**	**174.55**
	Group*Pictorial inferences	.32	1, 64	.57	.005	178.66

Note: ADHD= attention-deficit/hyperactivity disorder; TD= typically-developing group; CPT= Continuous Performance Test; ToM= theory of mind

revealed a significant contribution to social perception, especially for video and combined stimuli, in which facial recognition and eye gaze detection could make decoding easier (Mitchell & Phillips, 2015). It is worth noting that only contextual ToM was significantly related to social perception abilities in our study. Contextual ToM measures the ability to relate an emotion to a context (Korkman et al., 2007), and is strongly associated with social perception skills. Generally speaking, our result is consistent with studies showing that ToM has profound implications for complex social behaviors, and contributes to the development of prosocial attitudes (Knafo et al., 2008; Walker, 2005), both in children with ADHD and in their TD peers. Our finding contrasts, however, with previous reports that ToM does not correlate with social competence in ADHD populations (Charman et al., 2001). A possible explanation for this discrepancy might relate, at least in part, to differences in the sensitivity of the tests used in the various studies (Pineda-Alhucema et al., 2018). Most relied on parents' reports to assess social competence (Charman et al., 2001), without obtaining any behavioral measures of social perception. Our results also revealed that attention - not inhibition - was the variable most strongly associated with our groups' social perception skills in response to the different social stimuli. Attention was particularly important with the combined stimuli, as there were more different stimuli demanding attention than in the case of audio or video material alone. These findings diverge from previous reports suggesting that social deficits in ADHD are due mainly to behavioral inhibition problems (Barkley, 1997; Rapport et al., 2002; Uekermann et al., 2010). On the other hand, our findings are consistent with those of Semrud-Clikeman (2010), who also found attention (and not inhibition) problems related to social perception abilities. Finally, and as hypothesized, pragmatic language was particularly influential in the case of stimuli in which relevant information - such as lexical content or facial expressions - was intelligible (Socher et al., 2019). In fact, pragmatic language abilities are needed to infer from social settings (Russell, 2007). Surprisingly, the role of pragmatic language depending on the type of social stimulus presented differed between our two groups. The TD group's greater social perception abilities were thanks to their better performance on pragmatic tasks, whereas no significant associations emerged for the children and adolescents with ADHD. These results support the report from Staikova et al., (2013, pp. 12082) of different relations between pragmatics and social skills, depending on the domain of pragmatic language considered. Pragmatics is a heterogeneous construct that includes several skills, and can be divided into separate areas: discourse management (i.

e., the skills needed to initiate, maintain, and end a conversation), presupposition (i.e., assumptions and inferences about the other party in the conversation, and the social context), and narrative discourse (i.e., the ability to generate a successful narrative) (Adams, 2002; Landa, 2005). Staikova et al., (2013, pp. 12082) found that only discourse management, not presupposition or narrative discourse, related to social impairments in children with ADHD. The three areas of pragmatic language thus refer to distinct abilities, which may have specific implications for social perception and social functioning. For example, interrupting others in a conversation may have a more direct adverse effect on popularity among peers in childhood than difficulty understanding social context. It is worth noting that, in terms of the above-described classification, our pragmatic language measures focused more on presupposition than on discourse management.

Although our results seem interesting, further studies are needed to confirm and extend our findings, and to overcome several limitations of the present study. One such limitation concerns the fact that we relied on cross-sectional data rather than investigating the three higher-order domains over time, as the participants' social perception abilities developed. It may be that a better social perception promotes greater ToM abilities, and the attention and ToM domains may also influence each other in some way. A second limitation lies in that we only administered a limited set of measures for each cognitive domain. Further studies could include different measures of ToM, attention and executive functions, and communication skills. Thirdly, our samples' characteristics should be mentioned. A marked variability in participants' ages within each clinical sample was present. Although our groups were matched for, each ability develop during both childhood and adolescence, thus it is likely that the developmental trajectory of these abilities may assume specific features in each age step. Future studies might reduce this variability by adopting more restrictive criteria in order to analyze age groups in cross-sectional research. Moreover, males were disproportionately represented in our sample. This is hardly surprising, as sex differences in the incidence of ADHD have been well documented in the literature, with a reported male-to-female ratio of about 3:1 (Willcutt, 2012). Previous reports have also described males having more severe symptoms than females with ADHD. Further studies should nonetheless try to replicate our findings in larger samples of children with a similar proportion of male and female participants. Recruiting larger samples will also enable more generalizable results to be obtained, and possible differences between the inattentive and hyperactive/impulsive presentations of ADHD to be explored. Finally, although this study used direct assessments of social perception abilities, the children were not active participants in the situation, so we cannot draw any conclusions about the children's behavior in real life situations, or differences between their social knowledge and performance. Future studies should consider this relation in depth, since it remains to be seen whether children with ADHD show a global deficit in both components, as they may have an inconsistent social performance rather than just a lack of social knowledge (see for review de Boo & Prins, 2007; Aduen et al., 2018).

Even with the above-mentioned limitations, our findings have important clinical implications for both assessment and intervention. First, the social perception of children and adolescents with ADHD was only significantly worse than that of TD controls in tasks closely resembling real-life everyday interactions. This points to the importance of presenting tasks that are as similar as possible to real-life interactions during clinical assessments in order to capture the social perception profile associated with ADHD (Magill-Evans et al., 1995). Second, children with ADHD experiencing social perception problems may respond differently to interventions, depending on the reasons for their poor social skills. The main contribution of ToM and attention to social perception suggests that interventions need to address these abilities directly when working with children and adolescents with ADHD. For example, practitioners could indirectly promote their social perception by training their perspective-taking (Montoya-Rodríguez & Molina-Cobos, 2019) or attention (Tamm et al., 2010) skills.

8. Conclusions

Taken together, our findings are consistent with previous research (Beauchamp & Anderson, 2010; Fine et al., 2008; Semrud-Clikeman, 2010; Semrud-Clikeman et al., 2010) showing that higher-order cognitive skills (i.e., ToM, attention and inhibition, and pragmatic language) are essential to social perception in typical development and ADHD. Our results extend previous findings in that our children and adolescents with ADHD performed worse than TD controls in terms of social perception, but only in tasks resembling real-life everyday interactions. Nonverbal signal recognition scores and the type of social stimulus presented influenced social perception accuracy of both children with ADHD and TD controls. Attention emerged as the factor explaining the largest percentage of variance in their performance in social perception tasks, regardless of the type of stimulus presented. ToM also showed a contribution, especially in the case of stimuli containing visual information. Finally, pragmatic language was associated with social perception only in TD children and adolescents, not in those with ADHD.

CRediT authorship contribution statement

Ramona Cardillo: Conceptualization, Formal analysis, Writing - review & editing; **Giulia Crisci:** Conceptualization, Methodology, Formal analysis, Writing - original draft; **Stefano Seregni;** Data collection; Methodology. **Irene C. Mammarella:** Conceptualization, Supervision, Project administration; Writing - review & editing.

Statements and Declarations

none.

Competing Interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability

Data will be made available on request.

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GC and RC contributed equally to this work.
We declare that this article is part of the PhD project of GC, supervised by ICM.

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Ramona Cardillo: Postdoctoral fellow at the Department of Developmental and Social Psychology at the University of Padova, Italy. She has undertaken research on neurodevelopmental disorders and neuropsychological profiles in autism spectrum disorders without intellectual disability, and on non-verbal learning disability and ADHD.

Giulia Crisci: PhD student at the Department of Developmental and Social Psychology at the University of Padova, Italy. She is conducting research on social and cognitive processes in children and adolescents with ADHD, specific learning disorders and autism spectrum disorders.

Stefano Seregni: Psychologist and Psychotherapist at the AULSS2, Marca Trevigiana, Italy.

Irene C. Mammarella: Associate professor at the Department of Developmental and Social Psychology at the University of Padova, Italy. Her research interests include neurodevelopmental disorders, such as nonverbal learning disability, specific learning disorders, autism spectrum disorders and ADHD.