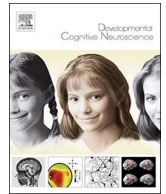




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Simulating interaction: Using gaze-contingent eye-tracking to measure the reward value of social signals in toddlers with and without autism

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ABSTRACT

Several accounts have been proposed to explain difficulties with social interaction in autism spectrum disorder (ASD), amongst which atypical social orienting, decreased social motivation or difficulties with understanding the regularities driving social interaction. This study uses gaze-contingent eye-tracking to tease apart these accounts by measuring reward related behaviours in response to different social videos. Toddlers at high or low familial risk for ASD took part in this study at age 2 and were categorised at age 3 as low risk controls (LR), high-risk with no ASD diagnosis (HR-no ASD), or with a diagnosis of ASD (HR-ASD). When the on-demand social interaction was predictable, all groups, including the HR-ASD group, looked longer and smiled more towards a person greeting them compared to a mechanical Toy (Condition 1) and also smiled more towards a communicative over a non-communicative person (Condition 2). However, all groups, except the HR-ASD group, selectively oriented towards a person addressing the child in different ways over an invariant social interaction (Condition 3). These findings suggest that social interaction is intrinsically rewarding for individuals with ASD, but the extent to which it is sought may be modulated by the specific variability of naturalistic social interaction.

1. Introduction

Understanding the origin of the social interaction difficulties encountered by people with an autism spectrum disorder (ASD), whether it results from atypical *orienting* towards social stimuli, from a decreased *motivation* to engage with them, or alternatively from difficulties *understanding* and interpreting social exchanges, possibly because of their variable and complex structure, has been a key question and a challenge in ASD research (Elsabbagh and Johnson, 2016). Social orienting accounts were inspired by developmental work on neonatal face orienting abilities (Goren et al., 1975; Johnson et al., 1991 Johnson et al., 1991) and proposed that impairments in underlying cortical or sub-cortical mechanisms in ASD, would lead to decreased exposure to faces and, eventually, to cascading effects on social learning and social interaction (Elsabbagh and Johnson, 2010). Social motivation accounts expanded this view by involving reward networks and their impairment in the aetiology of ASD (Chevallier et al., 2012b). According to some authors, stimuli rich in social interactive content are best at revealing the weaker social drive in ASD. Indeed, a decreased preference for

social stimuli is observed when using stimuli which depict people interacting with each other (Chevallier et al., 2015; Pierce et al., 2016; Shi et al., 2015), approaching (Crawford et al., 2016) or talking to the viewer (Dubey et al., 2015; Chawarska et al., 2013). More recently, an alternative but not exclusive theory of ASD was proposed, suggesting that social interaction difficulties may occur because of the statistical structure of such interactions. According to this account, when representing the world, individuals with ASD give too much weight to bottom-up inputs or to more recent events, to the detriment of priors computed on past events (i.e. hypo-priors, (Pellicano and Burr, 2012); low precision of prior information, (Friston et al., 2013)). One strategy for decreasing prediction error resulting from the inability to compute or give more weight to prior experience, is to preferentially engage with events that are less variable, therefore more predictable. As compared to objects driven by physical forces, interacting with human beings has a high degree of variability, both in terms of the timing and the content of responses (e.g. there are many different ways of greeting someone). Few studies have directly tested the impact that variability or predictability of an interaction has on social choices in ASD (Dawson et al.,

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1998). However, children with ASD exhibit more frequent social behaviours and social drive when interacting with familiar, therefore more predictable, social partners (e.g. caregivers) (Goldberg et al., 2016; Sigman et al., 1986). The decreased motivation towards social stimuli with rich interactive content documented above could also be reframed in terms of an aversion for more unpredictable stimulation.

To date, there is still little convergence within the findings to confidently support one hypothesis over another. This is partly due to the fact that many investigations into the origin of social interaction atypicalities were carried out in older children or adults. The profile of impairment in adulthood is likely to reflect idiosyncratic compensatory strategies or compounding effects resulting from a lifelong experiencing challenging social exchanges (Johnson et al., 2015). Difficulties with understanding social interactions, later in life, could be a consequence of reduced motivation to engage with others. The opposite scenario may be equally possible, difficulties with processing social cues, earlier in life, leading to decreased motivation to engage with social partners. Even when developmental populations have been considered, the paradigms employed did not always lead to conclusive interpretations. A large amount of research has measured the distribution of visual attention to scenes containing social agents or social interaction in early ASD (Chawarska et al., 2013; Elsabbagh et al., 2014; Jones and Klin, 2013; Pierce et al., 2011). For example, in, Pierce et al. (2011) 2-year-old children saw two movies displayed side by side, with one containing geometric shapes in movement and another video showing children playing. In this study, the ASD group looked less towards the social scenes than the control participants. Similarly, Jones and Klin (2013) reported a decrease in looking to people's eyes and faces in infants with ASD from 6 months on to 2 years of age. These differences in looking time to faces and social scenes are consistent with several accounts. They could reflect an impairment in social orienting (Klin et al., 2002), but could equally result from reduced attributed reward value of social stimuli (Chevallier et al., 2012b) or from difficulties predicting when this information becomes relevant (Vivanti et al., 2011). Other studies carried out with older children and adults with ASD, using similar methodology, also fall short from teasing apart between different interpretations (Riby and Hancock, 2008; Fletcher-Watson et al., 2008).

Because social signals are increasingly considered to induce similar responses as other reward stimuli do, i.e. motivational approach as well as hedonic response (Schultz, 2006), new experimental paradigms have been developed to isolate the reward value of social signals in typical development and ASD. In Dubey et al. (2015), contrary to typical adults, adults with ASD carried out less effortful actions to see a video of a person smiling towards them as opposed to a video of a smiling person with averted gaze or a video of an object, demonstrating less approach behaviour towards social stimuli. Ewing et al. (2013) measured for how long children with or without ASD would press a key to maintain a social or a non-social stimulus on a screen (i.e. face or car), but found no group differences. Variations in the experimental design can possibly affect how sensitive these tasks are at measuring group differences. Giving participants a choice between the types of interaction, as in Dubey et al., might have exacerbated the processing of social value of the stimuli. Notwithstanding these differences, paradigms using on-demand social stimulation seem well suited to tease apart motivational from other aspects of social interaction.

In the current work, we build on the above studies to test different accounts of atypical social interaction in ASD. An interactive eye-tracking task was used to examine whether toddlers with and without ASD engaged with and appreciated different types of simulated social interaction. Participants in this study were toddlers at high-risk for ASD due to having an older sibling with the disorder. Low-risk participants had no first-degree relative ASD. About 20% of high-risk participants go on to develop ASD themselves (Ozonoff et al., 2015; Messinger et al., 2015). Another 20% will manifest subthreshold symptoms of the disorder (Messinger et al., 2013) and the remaining children will have typical development.

With the use of a gaze-contingent paradigm, toddlers had the possibility to animate one of two different videos through their gaze behaviour. Importantly, the current study manipulated both the social content and the predictable nature of the simulated interaction using different social stimuli in three different conditions. In a first condition (*Face vs. Toy*), toddlers could choose between a social stimulus (a person greeting and smiling) and a non-social stimulus (a spinning musical *Toy*). In contrast to the paradigm used by Pierce et al. (2011), the stimuli were animated when the participant oriented towards them. According to the social orienting and social motivation theories, typically developing toddlers (low risk of autism) should preferably orient towards the social stimulus but toddlers with ASD should show no preference or prefer the spinning toy (Table 1). A second condition (*Towards vs. Away*) contrasted two social stimuli that, when looked at, displayed either a person turning and smiling towards the participant or a person turning away from the participant. According to the social motivation theory of autism, typically developing toddlers but not toddlers with ASD should preferably orient towards the more engaging social stimulus (Table 1). Finally, a third condition (*Invariant vs. Variable*) manipulated the variability of the social response received: an invariant interaction (showing the same clip in which a person addresses the child with Hello) was contrasted with a variable social stimulus (the person either saying Hello, Good job or smiling silently). According to the hypo-priors account, toddlers with ASD should show a preference for the invariant interaction (Table 1).

2. Methods

2.1. Participants

Participants in this study were toddlers with or without familial risk for ASD, a proportion of whom were later diagnosed with ASD at age 3. 116 High-Risk (HR) participants (52 females) who had at least one older sibling with a community clinical diagnosis of ASD and 27 Low-risk (LR) participants (13 females) who had no first-degree relative with ASD enrolled in the study. All HR and LR children were full term infants (gestational ages of 38–42 weeks) recruited from a volunteer database at the Birkbeck Centre for Brain and Cognitive Development. Families attended four lab visits at 9, 15, 27 and 36 months. The experimental data reported here has been collected on a subset of these children during the 27-month visit and the clinical diagnosis was obtained during the 36-month visit (Table 2, see SOM for detailed clinical measures). Of the 116 HR enrolled in the study, 92 took part in the experiment and provided valid data (additional criteria of exclusion are explained later in this section) and also attended the 36-month visit. Experienced clinical researchers (TC, GP) reviewed information on ASD symptomatology (ADOS-2 (Lord et al., 2012), ADI-R (Lord et al., 1994), SCQ (Rutter et al., 2003)), adaptive functioning (Vineland Adaptive Behavior Scale II, (Sparrow et al., 2005), and development (Mullen Scales of Early Learning, (Mullen, 1995)) for each HR and LR child to

Table 1

Predictions based on three explanatory models: Diminished social orienting account (Klin et al., 2002), Diminished social motivation account (Chevallier et al., 2012b), Hypo-priors account (Pellicano and Burr, 2012). These accounts make different predictions about performance in this study. The symbol 'x' indicates the conditions under which the HR-ASD group performance would differ from the LR controls, according to the different explanatory models.

Explanatory models of atypical social attention in ASD	Condition 1	Condition 2	Condition 3
	Face vs. Toy	Towards vs. Away	Variable vs. Invariant
Diminished social orienting	x		
Diminished social motivation	x	x	
Hypo-priors (predictability)			x

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