Social Bayes: Using Bayesian Modeling to Study Autistic Trait–Related Differences in Social Cognition

Meltem Sevgi, Andreea O. Diaconescu, Marc Tittgemeyer, and Leonhard Schilbach

ABSTRACT

BACKGROUND: Autism is characterized by impairments of social interaction, but the underlying subpersonal processes are still a matter of controversy. It has been suggested that the autistic spectrum might be characterized by alterations of the brain's inference on the causes of socially relevant signals. However, it is unclear at what level of processing such trait-related alterations may occur.

METHODS: We used a reward-based learning task that requires the integration of nonsocial and social cues in conjunction with computational modeling. Healthy subjects ($N = 36$) were selected based on their Autism Quotient Spectrum (AQ) score, and AQ scores were assessed for correlations with model parameters and task scores.

RESULTS: Individual differences in AQ were inversely correlated with participants' task scores ($r = -.39$, 95% confidence interval [CI] [−.68, −.13]). Moreover, AQ scores were significantly correlated with a social weighting parameter that indicated how strongly the decision was influenced by the social cue ($r = -.42$, 95% CI [−.66, −.19]), but not with other model parameters. Also, more pronounced social weighting was related to higher scores ($r = .50$, 95% CI [.20, .86]).

CONCLUSIONS: Our results demonstrate that higher autistic traits in healthy subjects are related to lower scores in a learning task that requires social cue integration. Computational modeling further demonstrates that these trait-related performance differences are not explained by an inability to process the social stimuli and its causes, but rather by the extent to which participants take into account social information during decision making.

Keywords: Autistic traits, Bayesian modeling, Computational psychiatry, Reward-based learning, Social cognition, Social gaze

http://dx.doi.org/10.1016/j.biopsych.2015.11.025

Autism is characterized by profound impairments of social interaction and communication. These difficulties are thought to be related across the diagnostic divide to autistic trait–related differences in social perceptual or cognitive abilities (1). It has become clear in recent years that a striking dissociation exists between relatively intact explicit and severely impaired implicit social abilities (2). In other words, high-functioning individuals with autism learn to explicitly think about other persons' mental states, yet they still find it very difficult to engage in real-time social interactions with people without autism (3,4). Exactly which subpersonal processes show autistic trait–related differences and could explain everyday life social impairments is still a matter of substantial controversy. Recent studies have provided evidence that many putatively relevant processes, such as action perception, are intact in autism (5). Still, individuals with autism have striking impairments in social situations in everyday life, which raises the question of which and how processes other than basic perceptual mechanisms may come into play (6).

A currently prominent theoretical suggestion includes the assumption that the autistic spectrum might be specifically characterized by deficits of predictive coding or Bayesian inference (7,8). Predictive coding formulations of perception propose that expectations in higher brain areas generate top-down predictions that meet bottom-up, stimulus-related signals from lower sensory areas. The discrepancy between actual sensory input and predictions of that input is described as a prediction error. With regard to autism, it has been proposed that autistic traits might be related to higher sensory precision (i.e., a stronger reliance on [bottom-up] sensory evidence as opposed to [top-down] prior beliefs), which can lead to a failure of automatically contextualizing sensory information in an optimal and socially adequate fashion (9,10). Furthermore, the reliance on prior beliefs rather than sensory information might be particularly relevant in situations of high uncertainty, such as direct social interactions with others, as social agents are arguably the most difficult "things" to predict (10). This theoretical proposition resonates with clinical descriptions of patients with autism as having a particular dislike for situations of direct social interaction with others, whereas situations of social observation are described as less difficult (4).

SEE COMMENTARY ON PAGE 87

 ISSN: 0006-3223

In light of recent findings that demonstrate relatively intact perceptual processes in autism, it might be precisely the integration of bottom-up and top-down processes during social interactions and exploitation of social cues provided by others during decision making that could be particularly relevant to understanding the social impairments in autism. In other words, although autistic traits may not be associated with disturbances of basic perceptual and learning processes, it is conceivable that such traits may affect whether and to what extent social information influences decision making and what behavior is actually shown. From a predictive coding perspective, there are two possible pathologies. There could be deficits in predicting and inferring the mental states of others, or, alternatively, these inferences could be unable to influence behavior because they are afforded an impoverished weight or precision.

Recent progress in computational modeling has demonstrated that Bayesian models can be used to formally investigate perceptual and cognitive mechanisms that underlie social behavior when explicit social advice is provided to study participants (11). In particular, it has been shown that humans employ hierarchical generative models to make inferences about the changing intentions of others when attention is explicitly directed toward them and that they integrate estimates of advice accuracy (i.e., the correctness of the advice, which can be valid or misleading depending on the conflicting interests of the players) with nonsocial sources of information when making decisions. In Bayesian terms, this integration corresponds to an optimal weighting of prosocial and nonsocial cues in terms of their relative precision when making decisions.

In the present study, we build on this research by applying hierarchical Bayesian modeling to behavioral data from a novel version of a probabilistic learning paradigm. This paradigm included a social gaze cue about whose relevance no explicit information was provided in order to investigate autistic trait–related differences in the extent to which healthy individuals integrate and use this piece of social information during task performance. We hypothesized that autistic traits are related to differences in the extent to which individuals are influenced by social cues (i.e., their precision), rather than a general inability to process social cues and their putatively underlying mental states. On the behavioral level, this hypothesis should result in higher total task scores for individuals lower in autistic traits, as they should be more easily able to exploit the additional social information. In terms of the underlying cognitive processes, we hypothesized that this behavioral advantage might be subserved by differences in the effect that social information has on decision making, which would be inversely related to autistic traits. We further predicted that using the social cue should be more difficult under volatile conditions and differentially so for individuals with higher autistic traits.

METHODS AND MATERIALS

Participants

In light of evidence suggesting that autistic traits are distributed as a continuum across the general population and are known to show identical etiology across the diagnostic divide (1), we chose to study healthy participants based on their score on the German translation of the Autism Quotient Spectrum (AQ) questionnaire (12). This experimental approach of studying autistic traits in neurotypical subjects makes it possible to make inferences about the etiology of autistic traits without potential confounds from various comorbid conditions often noted in patients with autistic spectrum disorders. To capture the extremes of the distribution and have a balanced proportion of participants with high and low AQ scores, 36 subjects were prescreened and invited to participate based on their AQ scores up to 25 (19 men; age range, 20–37 years; mean age 26.25 years). It has been shown that AQ has good discriminative validity at a threshold of 26 (13). Participants did not have any history of neurologic and psychiatric disorders and were recruited by using a preexisting database of the Max Planck Institute for Metabolic Research comprising healthy native German volunteers. The distribution of AQ scores was as follows: range, 7–23; mean 15.72; SD 5.09. All participants gave informed consent before the beginning of the experiment.

Experimental Paradigm

The card game used in our study, which had been originally designed as two cards with associated winning probabilities (14,15), was combined with a face cue presented in the center of the screen (Figure 1A). The eye gaze direction of the face was manipulated to change during each trial and to be directed toward one of the cards before participants were allowed to make their choice. As a result, two things needed to be learned in the task: first, whether the reward is associated with the green card or the blue card; second, whether the gaze shift is directed toward the card that is rewarded. The probability of whether or not the face actually looked toward the winning card on a given trial (i.e., gaze accuracy) was systematically manipulated in accordance with a probabilistic schedule as well (Supplement). Both the card and the gaze accuracies were varied independently of one another (Figure 1B, C). The phases in which the trials have cues with unstable accuracy are referred to as volatile phases. In the first half of the experiment (trials 1–60), card accuracy was stable and high, whereas in the second half (trials 60–120), it followed a volatile phase. For the gaze accuracy, the volatile phase took place during trials 30–70. The probabilistic schedule for the gaze accuracy was reversed for half of the subjects to avoid block order effects. Positions of the cards (left or right) were determined randomly.

In the instructions, subjects were informed about the cards' having winning probabilities, which could change during the experiment and which were independent of the reward magnitude that was displayed on them. On each trial, there would be only one correct card, and if subjects chose the correct card, they would receive the score (random numbers between 1 and 9) that had been displayed on it. Subjects were instructed that they would earn an extra amount of money depending on their score at the end of the experiment. Finally, participants were informed about the presence of a face on the screen, which was explained by stating that it was supposed to make the visual display "more interesting." Participants did