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Autism does not limit strategic thinking in the "beauty contest" game

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ABSTRACT

A popular hypothesis in developmental psychology is that individuals with autism spectrum disorder (ASD) have a specific impairment or developmental delay in their ability to reason about other people's mental processes, especially when this reasoning process is of a higher-order, recursive, or nested variety. One type of interpersonal interaction that involves this sort of complex reasoning about others' minds is an economic game, and because economic games have been extensively modeled in behavioral economics, they provide a unique testbed for a quantitative and precise analysis of cognitive functioning in ASD. This study specifically asked whether ASD is associated with strategic depth in the economic game known as The Beauty Contest, in which all players submit a number from 0 to 100, and the winner is the player who submits the number closest to 2/3 of the mean of all numbers submitted. Unexpectedly, the distribution of responses among adult participants with ASD reflected a level of strategic reasoning at least as deep as that of their neurotypical peers, with the same proportion of participants with ASD being characterized as "higher order" strategic players. Thus, whatever mentalistic reasoning abilities are necessary for typical performance in the context of this economic game appear to be largely intact, and therefore unlikely to be fundamental to persistent social dysfunction in ASD.

1. Introduction

Successful social interaction requires one to understand and predict the actions of others, often by making inferences about their hidden mental processes. This is the practical application of one's theory of mind (ToM) or "mentalizing" ability. ToM involves the representation of another person's mental states (e.g., beliefs, goals, intentions), to enrich one's internal model (or subjective *theory*) of how another person's mind works, and how this hidden inner world indirectly connects to observable actions and behaviors.

Social interactions can sometimes be competitive in nature—" games" in which the right decision inherently depends on the adopted strategies of the other "players." When certain assumptions have been made about the structure of a game (i.e., the number of players in the game, the nature of the possible "moves," and the payoffs each player will receive depending on various outcomes of the game), game theory prescribes the normatively rational strategy with which to play it. Although not all games have multiple players, many canonical economic games do (e.g., the prisoner's dilemma and the stag hunt), and the game theoretic analyses of these games can provide insight into the choices agents make in interpersonal situations.

To the extent an agent treats other players as having minds, and makes decisions on the basis of how the mental states of others relate to their actions, strategic thinking in these situations bears a resemblance to traditional psychological characterizations of ToM (cf. Abell, Happé, & Frith, 2000; Dennett, 1987; Leslie, 1994). Both faculties involve reasoning about the thought processes of other people, often in a recursive or nested manner (e.g., "I think that he thinks that I think..."; Hedden & Zhang, 2002).

In a strategic scenario, game theory prescribes the optimal action, based on the rules of the game and the set of possible outcomes. But in practice, an advantage can sometimes be gained if one brings additional assumptions to bear on the interaction—for example, assumptions about just *how* sophisticated one's adversaries are. In the analysis of these situations, the study of economics and ToM truly synthesize into a field known alternatively as "behavioral game theory," "game theory of mind," or "social decision making" (see Camerer, 2008; Gariépy, Chang, & Platt, 2013; Hedden & Zhang, 2002; Lee, 2008; Yoshida, Dolan, & Friston, 2008). Whereas orthodox game theory assumes the rationality of all players, behavioral game theory treats the level of rationality of the players as a variable to be estimated by each player in the game—and, ultimately, the researcher who is studying their behavior. Because estimating the inner workings of other

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people's minds indeed defines ToM, the connection between these two disciplines is clear, though often tacit (Baker, Saxe, & Tenenbaum, 2009; Pantelis et al., 2016). This study further explores the insights behavioral game theory can offer to the understanding of ToM, in both typical and atypical development.

1.1. Autism and theory of mind

Autism spectrum disorder (ASD) is, by its very clinical definition, characterized by a disruption of the faculties recruited for successful social interaction (American Psychiatric Association, 2000, 2013). A longstanding hypothesis in developmental psychology is that the root of this dysfunction is an impairment or developmental delay in ToM—especially the higher-order, complex variety (Baron-Cohen, 1989; Baron-Cohen, Leslie, & Frith, 1985). By adulthood, higher-functioning adults often improve to typical performance on canonical tests of ToM (e.g., the classic "Sally-Anne" false belief task), at least when presented with an explicit task in a laboratory setting (Schneider, Slaughter, Bayliss, & Dux, 2013; Senju, Southgate, White, & Frith, 2009). Other experimental paradigms are sensitive to apparently persistent—albeit sometimes latent—deficits in this domain (Castelli, Frith, Happé, & Frith, 2002; Moran et al., 2011).

To preface a point of later discussion, not all agree that any of these just-mentioned experimental tasks are true demonstrations of ToM, strictly construed. It has been argued that typical performance in the vast majority of tasks presumed to require the attribution of mental states in another (such as beliefs and desires) can also be achieved by application of learned (or innate) behaviorist-style input-output rules that map the observed situation of another to the predicted action (Heyes, 2014; Penn & Povinelli, 2007; Perner, 2010; Perner & Ruffman, 2005). We will revisit this topic in the *Discussion* with specific respect to the task we present in this study.

That said, reasoning about other people's thought processes to predict their actions lies at the heart of both ToM and strategic thinking, and this has naturally led interdisciplinary researchers to wonder how people with ASD approach economic games (Ewing, Caulfield, Read, & Rhodes, 2015; Kashner, 2014; Kishida, King-Casas, & Montague, 2010; Sally & Hill, 2006; Tayama et al., 2012; Yoshida et al., 2010). However, experimental data on this topic are surprisingly scarce. This study continues down this path of inquiry with the analysis of an economic game called The Beauty Contest.

1.2. The beauty contest

Each player submits a whole number from 0 to 100. The winner is the player who submits the number closest to 2/3 of the mean of all numbers submitted (Nagel, 1995; the fraction used varies from study to study, but 2/3 is popular because using this fraction allows one to successfully decouple a strategy of answering at the middle of the scale [in this case, 50] from one in which one takes the fraction used times the max of the scale [in this case, ~67]). The Nash equilibrium (i.e., game theoretic solution) for this game is the result of a repeated undercutting process that ultimately prescribes that the rational actor should select 0—as should all of the other players.[1] Everyone wins.

Empirically, however, choosing the normative solution of 0 only allows for a moral victory. Sampling from a variety of populations—from U.S. high school students to economics PhDs (Camerer, Ho, & Chong, 2004)—the mean response is typically between 25 and 35, making the winning response ~20. To actually win the game in practice, one must estimate just *how* close opponents' strategies will be to the "rational" choice of 0—or get very lucky.

When approaching this game, players may adopt strategies in which they explicitly reason about the *beliefs that other players have about other players' beliefs*, and the strategies the other players will employ based on those beliefs. Multiple behavioral game theoretic approaches have explicitly modeled this game in this fashion, additionally allowing that although some players will reason in this mentalistic manner, others will forego this approach in favor of a simpler strategy.

1.3. Mentalistic and non-mentalistic strategies in the beauty contest

The various strategies one may bring to the Beauty Contest require one to think mentalistically about the other players in the game to varying extents. Some answer randomly ("0th order" players) or assume that others will do so ("1st order" players). Others employ "higher-order" strategies that involve *beliefs* about other people's *beliefs*, and their *policies* or *strategies* in connecting these beliefs to actions. To the extent that players produce responses consistent with these higher-order strategies, we argue that they are more likely to be engaging something closely akin to ToM (see also Goodie, Doshi, & Young, 2012).

This account of a typical distribution of strategies employed by players in the Beauty Contest—with its explicit appeals to a ToM framework, in which some players explicitly take into account presumptions about others' beliefs and their policies for acting on those beliefs—can be straightforwardly and intuitively converted into a quantitative model (Camerer et al., 2004; Nagel, 1995). The intuitive elegance of these models and their ability to fit actual human behavior in the Beauty Contest (both qualitatively and quantitatively), often with as few as one free parameter, has been one of the clearest successes of the behavioral game theoretic approach as an explanatory and predictive psychological theory, and provides evidence for their validity.

1.4. Quantitative modeling approach

Nagel (1995) and Camerer et al. (2004) model the typical distribution of responses in the beauty contest as reflecting variability in the number of "cognitive steps" people are willing or able to take. The number of steps taken by the individual defines the "order" of the strategy. 0th order players answer randomly (or by some arbitrary criterion). 1st order players assume everyone else will submit random numbers (on average, 50), and therefore submit an answer of $(2/3) * 50 \approx 33$. 2nd order players assume they are playing against a mixture of 0th and 1st order players, and higher order players are defined recursively from there.

The Camerer et al. (2004) model assumes that a kth order player has an accurate belief about the proportions of players taking on lower-order strategies, but does not believe any of the other players will adopt kth and higher-order strategies. The Nagel (1995) model assumes that kth order players believe all other players will adopt a $k-1$ order strategy (see also Coricelli & Nagel, 2009).

Under the Camerer et al. (2004) model, strategies are distributed according to the Poisson distribution, defined by a single λ parameter (equivalent to both the mean and variance of the orders of strategy adopted by the players). Their model is fully specified by this one parameter, and can fit the present study's data well qualitatively, namely predicting peaks in the response distribution at the appropriate places. However, for better quantitative fits (as measured by the likelihood of beauty contest responses under the model) we instead employ a variation on Nagel (1995).

As in Nagel (1995), our model assumes that kth order players believe all other players will adopt a $k-1$ order strategy. The

[1] Technically, if players are only allowed to submit integer values (as in this paper), all players submitting 1 is also a Nash equilibrium for this game (Bosch-Domènech, Montalvo, Nagel, & Satorra, 2002).