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Abstract

This study investigated vicarious effort-based decision-making in 50 adolescents with autism spectrum disorders (ASD) compared to 32 controls using the Effort Expenditure for Rewards Task. Participants made choices to win money for themselves or for another person. When choosing for themselves, the ASD group exhibited relatively similar patterns of effort-based decision-making across reward parameters. However, when choosing for another person, the ASD group demonstrated relatively decreased sensitivity to reward magnitude, particularly in the high

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Author Contributions MM and GD conceived of the study, participated in its design and coordination, participated in data collection, conducted statistical analyses, and jointly drafted the manuscript. MT conceived of the study, participated in its design and coordination, and jointly drafted the manuscript. CD and HR participated in its design and coordination and jointly drafted the manuscript. JK, SM, JS, and RG participated in data collection. NDM and MB consulted on statistical analyses.

Compliance with Ethical Standards

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed Consent
Informed consent was obtained from all individual participants included in the study.

magnitude condition. Finally, patterns of responding in the ASD group were related to individual differences in consummatory pleasure capacity. These findings indicate atypical vicarious effort-based decision-making in ASD and more broadly add to the growing body of literature addressing social reward processing deficits in ASD.

Keywords

Autism spectrum disorder; Vicarious reward; Effort-based decision-making; Social motivation

Introduction

Current definitions of autism spectrum disorders (ASD; American Psychiatric Association 2013) emphasize impairments in social communication as a core deficit, including impairments in social cognition, social attention, joint attention, and theory of mind (ToM; e.g., Baranek 1999; Baron-Cohen et al. 2001; Dawson et al. 2004; White et al. 2009). Recent evidence highlights that deficits in social motivation may contribute to social communication impairments in ASD such that, under certain motivational conditions, social communicative abilities appear to be unimpaired in ASD (Chevallier et al. 2012; Lahaie et al. 2006; Wang et al. 2004). Accordingly, the "social motivation hypothesis of autism" suggests that early-emerging disruptions in social motivation may be a primary deficit in ASD with downstream effects on the development of social communicative skills (Chevallier et al. 2012; Dawson et al. 2004). According to this model, individuals with ASD display social motivation deficits from infancy that persist through early childhood that impede the development of social functioning. In other words, social communication deficits in ASD may be influenced by decreased pleasure derived from social stimuli and/or contexts ("reward liking"), as well as diminished anticipation of social rewards ("reward wanting"; Chevallier et al. 2012).

The purpose of the present investigation was to evaluate vicarious effort-based decision-making to address one aspect of the social motivation hypothesis of ASD. Few studies on social motivation impairments have examined motivation in the context of effortful behavior. Preclinical studies have demonstrated a "law of least effort," namely that model organisms choose to exert the least amount of effort necessary to obtain a reward; however, when reward preferences increase, due to reward magnitude for instance, the organism will exert more effort to obtain such a reward (Salamone 2006; Solomon 1948). Factors influencing effort exertion include: perceived effort required, valuation of potential rewards, and the probability that the reward will be received if the organism is successful at completing the task (Salamone 2006). The Effort-Expenditure for Rewards Task (EEfRT) is an assessment that is sensitive to these motivational processes and mimics classic preclinical behavioral tasks that assay behavioral output of the mesolimbic dopaminergic system (Treadway et al. 2009; Treadway & Zald 2011).

The EEfRT has been used to examine motivational processes in nonclinical and clinical populations. Performance on the EEfRT was shown to be modulated by the administration of D-amphetamine, a dopamine agonist, such that it enhanced willingness to exert effort in a nonclinical sample (Wardle et al. 2011). In clinical samples, individuals with anhedonia and/or major depressive disorder showed decreased sensitivity to reward parameters on the EEfRT, consistent with preclinical models linking anhedonia to decreased mesolimbic dopamine function (Treadway et al. 2009, 2012). Additionally, the EEfRT was found to be a valid and reliable measure of effort expenditure for rewards in individuals with schizophrenia (Reddy et al. 2015). Finally, Damiano et al. (2012) found patterns of effort-based decision-making in adults with ASD characterized by overall more hard task choices to expend effort to obtain rewards regardless of reward contingencies (i.e., probability and magnitude).

Whereas the EEfRT has been used to measure effort-based decision-making when earning rewards for oneself, the current study sought to examine effort-based decision-making when earning rewards for others in adolescents with ASD. Experiencing pleasure when observing others achieve positive outcomes is a phenomenon called vicarious reward (Braams et al. 2014; Lockwood et al. 2015; Mobbs et al. 2009). Several studies have shown that the mesolimbic dopamine system is activated in nonclinical samples during vicarious reward conditions (Braams et al. 2014; Lockwood et al. 2015). Neuroimaging studies have found activity in the anterior cingulate cortex (ACC) exclusively for cues that are predictive of reward for others (Apps et al. 2016; Lockwood et al. 2015). Additionally, activity increases in this region when the benefit (or value) associated with a behavior is greater; that is, activity increases when another person will obtain a reward. Conversely, activity in the ACC also decreases with costs that decrease motivation, including effort costs or temporal delays (Apps et al. 2016). Therefore, the ACC signals the motivational value of vicarious reward in individuals who are typically functioning. In ASD, there is evidence of disruptions to the functional properties of the ACC (Balsters et al. 2017; Chiu et al. 2008), which may suggest social cognition deficits in part reflect atypical vicarious reward processing. However, there have been no studies that have investigated vicarious reward processing in ASD. In the present study, we investigated vicarious reward processing in adolescents with ASD using a modified version of the EEfRT that includes both standard and vicarious reward conditions.

Based on findings from Damiano et al. (2012), primary hypotheses predicted that, when making choices to earn rewards for themselves, adolescents with ASD would select the hard task option relatively more often than would the control group. Furthermore, given that ASD is characterized by deficits in prosocial behaviors (Dawson et al. 2012), it was hypothesized that the ASD group would have more pronounced deficits when making choices to earn rewards for another person (i.e., the vicarious reward condition) relative to when making choices to earn rewards for themselves. Finally, in exploratory analyses, linkages between effort-based decision-making and symptom severity, as well as dimensions of affect and reward sensitivity, were examined.

Methods

The UNC-Chapel Hill biomedical institutional review board approved this study. Prior to participation, informed consent was obtained from caregivers and adolescents over 18 years of age and assent was obtained from adolescents under 18 years of age.

Participants

Fifty adolescents with ASD and 32 typically developing controls (TDCs) 12–20 years old participated in the study which was approved by and in accordance with the ethical standards of the local institutional research committee at UNC-Chapel Hill and with the 1964 Helskinki declaration and its later amendments or comparable ethical standards. Participants with ASD were high functioning, defined as having fluent phrase speech and nonverbal IQ > 70. Both groups had no known sensory deficits nor diagnosis of intellectual disability. Additional inclusion criteria for the TDC group included: no diagnosis of ASD and lifetime-free of other Axis I diagnoses assessed via the Mini-International Neuropsychiatric Interview (MINI), self-report, administered to participants 18–20 years old, and the MINI for Children and Adolescents (MINI-KID-P), administered to caregivers of participants 12–17 years old. Participants with ASD were recruited via the UNC Autism Research Registry, a resource at the Carolina Institute for Developmental Disabilities (CIDD). Typically developing adolescents 12–17 years old were recruited via the UNC CIDD Child Development Registry whereas those 18–20 years of age were recruited via a UNC listserv for UNC employees and via the Human Participation in Research Subject Pool available through the UNC Department of Psychology and Neuroscience.

Table 1 provides participant demographic information. Groups did not differ in age, $t(80) = 0.64$, $p = .53$, or Performance IQ (PIQ), $t(79) = 1.72$, $p = 0.09$. Groups did differ in Verbal IQ (VIQ), $t(79) = 2.43$, $p = 0.02$, Full Scale IQ (FSIQ), $t(79) = 2.37$, $p = 0.02$, and gender distributions, $X^2 (2, N = 82) = 10.67$, $p < 0.01$. Groups did not differ on race and ethnicity distributions, $p > 0.05$ (ASD group: 45 Caucasians, 4 African Americans, 1 Hispanic; TDC group: 21 Caucasians, 6 African-Americans, 2 Asian Americans, 2 Hispanics). 68% ($n = 34$) of the ASD group met criteria for at least one comorbid disorder. 62% of adolescents with ASD were taking medications that fell into the following categories: antidepressants, psychostimulants, and atypical and typical antipsychotics. The majority of participants were post-pubertal (ASD = 81.25%; TDC = 83.33%, $p > 0.05$).

Groups significantly differed on the SRS, $t(80) = 12.40$, $p < 0.0001$, with greater social impairment reported in the ASD group compared to the TDC group. Importantly, the mean t score for the TDC group fell within the normal range while the mean t score for the ASD group fell above the clinical cut off (within the severe range). Groups also significantly differed on the TEPS Consummatory subscale, $t(80) = 2.38$, $p = 0.02$, with lower ratings of consummatory pleasure reported in the ASD group compared to the TDC group (summary statistics for these measures are presented in Table 2).

Procedure

Following consent, the EEfRT task, diagnostic, demographic, and symptom assessments, and cognitive tests were administered. The EEfRT task and symptom questionnaires were completed on a computer, the former using MatLab software, and the latter using Qualtrics survey software. Participants received a base rate of $10, plus $10 per hour for the 2–4 h testing session, plus an additional $2.00–8.66 earned during the EEfRT task (described below).

Materials and Measures

Effort-Based Decision-Making Task

Participants completed a modified version of the EEfRT (Damiano et al. 2012; Treadway et al. 2009; Treadway & Zald 2011), the “Self and Other” EEfRT (see Fig. 1). On each trial, participants chose between two levels of task difficulty, a “hard task” and an “easy task.” The hard task required participants to make 100 button presses within 21 s using his/her non-dominant pinky finger. The easy task required participants to make 30 button presses within 7 s using his/her dominant index finger. Each button press raised the level of a virtual bar, and raising this bar to the top of the display within the given time period denoted successful task completion, indicating that they were eligible to win money for that trial. Prior to each trial, participants were provided with three pieces of information about that trial: (1) the magnitude of the reward they could win; (2) the probability that they would receive the reward if they completed the trial successfully; and (3) if the trial was a “Self” or “Other” trial.

Reward magnitude varied as follows. For easy-task trials, participants were eligible to win $1.00 if they successfully completed the trial. For hard task choices, participants were eligible to win between $1.24–$4.30 if they successfully completed the task: the small magnitude condition varied in rewards between $1.24 and $2.00; the medium magnitude condition varied in rewards between $2.01 and $3.00; and the large magnitude condition varied in rewards between $3.01 and $4.12.

Reward probability varied as follows. At the beginning of each trial, participants were told whether they had a high (88%), medium (50%), or low (12%) probability of receiving a reward if they completed the task successfully. There were equal proportions of each probability level across the experiment, and each level of probability appeared once along with each level of reward value (Treadway et al. 2009).

Finally, at the beginning of each trial, participants were told whether they could earn money for themselves (“choosing for self,” standard condition) or for an another person whom they had not met (i.e., the next participant in the study; “choosing for other,” vicarious reward condition). They were also informed that a previous participant already earned money for them. Trial types (varying in reward magnitude, reward probability, and reward recipient) were presented in the same randomized order for every participant and choice periods were untimed (i.e., participants had as long as they liked to make their choices). Participants were told that two of their winning trials would be randomly selected at the end of the experiment for which they would receive the actual amount of money won during those two trials, which ranged from $2.00 to $8.66. At the end of the task, participants were told how much they earned for themselves and for the other participant. This final step served as another opportunity to remind participants that the “other participant” was the next participant in the study. Participants were also informed how much the previous participant had earned for them.

Prior to the experimental trials, participants were given detailed instructions about the task followed by several practice trials. To ensure task comprehension, experimenters asked participants to respond to questions regarding the task throughout the instructional period. If participants did not answer correctly, instructions were repeated until comprehension was confirmed.

Diagnostic Assessments

ASD diagnoses were confirmed via Modules 3 or 4 of the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et al. 2012) administered by a research reliable assessor and using standard algorithm cutoffs for ASD. To assess for past or present Axis I psychopathology, all participants completed either the MINI or the MINI-KID-P, semi-structured clinical diagnostic interviews that evaluate the presence of DSM-IV and ICD-10 psychiatric disorders in adults and in children and adolescents ages 6–17 via parent interview, respectively (Sheehan et al. 1998, 2010).

Cognitive Assessment

Intellectual functioning was assessed using the Wechsler Abbreviated Scale of Intelligence (WASI) for participants 18–20 years old, or the Kaufman Brief Intelligence Test, Second Edition (KBIT-2) for participants 12–17 years old, both reliable brief measures of intelligence that can be administered in ~30 min to yield Verbal IQ, Performance IQ, and Full Scale IQ scores. The WASI is an abbreviated version of the full Wechsler Adult Intelligence Scale (WASI; Axelrod 2002) and the KBIT-2 is an abbreviated version of the full Kaufman Assessment Battery for Children (KABC-II; Kaufman & Kaufman 2004). Both have been used in ASD samples (Bardikoff & McGonigle-Chalmers 2014; Damiano et al. 2012).

Autism Symptoms

Group means for symptom severity, affective functioning, and reward sensitivity are presented in Table 2. The Social Responsiveness Scale (SRS) is a self-report instrument that provides a dimensional measure of autism impairments. The 65-item rating scale measures the severity of social-communicative autism symptoms as they occur in natural social settings (Constantino et al. 2003). Participants responded on a four-point Likert scale, representing a range from "not true" to "almost always true." T scores from 60 to 75 are considered to be in the mild to moderate range while scores above 76 are considered to be in the severe range of impaired social functioning. The self-report version of the SRS (SRS-SR) was completed by adult participants (18–20 year olds); caregivers completed the caregiver-report version of the SRS (SRS-CR) for participants younger than 18 years old.

Anhedonia and Reward

The Temporal Experience of Pleasure Scale (TEPS) measures, on a scale of 1–5, how true a particular statement is for an individual, with 1 being "very false" and 5 being "very true." Items include "I appreciate the beauty of a fresh snowfall" and "When something is coming up in my life, I really look forward to it" (Gard et al. 2006). The measure comprises of nine items for each of the two scales, consummatory pleasure and anticipatory pleasure, and was administered to all participants with and without ASD. Total scores were generated for the two subscales with higher scores indicating greater levels of pleasure.

The Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) is a response item questionnaire with 48 yes/no items comprising 24 items for each of the two scales: sensitivity to punishment (SP) and sensitivity to reward (SR; Torrubia et al. 2001). For the purposes of the current study, only the sensitivity to reward subscale was analyzed, with higher scores indicating greater sensitivity to reward. For both groups, 18–20 year old participants filled out the self-report version (SPSRQ-SR) and caregivers filled out the caregiver-report version (SPSRQ-CR).

Affective Functioning

The Beck Depression Inventory-II (BDI-II) is a reliable measure of depressive symptoms (Beck et al. 1996). This measure was administered to 18–20 year-olds. The Child Depression Inventory (CDI) assesses depressive symptoms in individuals between the ages of 7 and 17 years old (Helsel and Matson 1984) and was administered to participants in this age range.

Development

The Peterson Pubertal Development Scale (PPDS) is an informant-based measure, which asks caregivers to report the degree to which their child has advanced through age-dependent physical development and the normative behavioral changes that accompany this stage (Petersen et al. 1988). This was completed by caregivers of adolescents aged 12–17 years old.

Data Analytic Plan

A priori hypotheses investigated whether the ASD group differed from the TDC group with respect to their willingness to expend effort to obtain uncertain rewards for Self and for Other. As such, the primary omnibus analysis was a 2 (Group: ASD, TDC) × 3 (Magnitude: Small, Medium, Large) × 3 (Probability: Low (12%), Medium (50%), High (88%)) × 2 (Agency: Self, Other) repeated measures analysis of variance on the percentage of hard task choices. Effect sizes (partial eta-squared, η_p^2 for F statistics and Cohen's d for *t* tests) are reported. We considered examining (Self-Other) difference scores that would reflect the bias to make hard task choices for oneself relative to another person; however, because difference scores obscure whether effects are driven by aberrant scores in one condition or the other, difference scores were not used. Follow-up analyses examined between- and within-group differences within and across each level of Magnitude and Probability for Self and Other conditions separately. Gender and IQ were not covaried in the primary analysis (1) to allow for a direct comparison with results from adults with ASD in Damiano et al. (2012), and (2) because there are no published data documenting relationships between gender and IQ and EEfRT performance. Results with these covariates are reported in supplementary analyses (see Online Resource 1). Between- and within-group *t* tests were also conducted to examine potential differences in average response time overall and for Self relative to Other conditions.

Correlational analyses examined relations between effort-based decision-making and ASD symptoms and affective and reward sensitivity in the ASD group. Results do not survive a Bonferroni correction; therefore, results presented below are exploratory.

Supplementary materials also include an examination of choice variability (see Online Resource 2). Further, alternative analyses using generalized estimating equations (GEE) are included in the supplement (see Online Resource 3) as an additional analytic approach previously used in effort-based decision-making studies (Treadway et al. 2009, 2012). Finally, analyses examining difference scores are reported in Online Resource 4.

Results

EEfRT Analyses

The dependent variable of the EEfRT was the percentage of times the hard task was chosen. Centrally relevant to the study hypotheses, the omnibus repeated measures ANOVA performed on the percentage of hard task choices revealed an Agency × Group × Magnitude interaction, $F(2,79) = 3.79$, $p = 0.03$, $\eta_p^2 = 0.04$, reflecting that groups differed on the influence of Magnitude in the Self relative to the Other condition. Additionally, there was an Agency × Group interaction, $F(1,80) = 3.88$, $p = 0.05$, $\eta_p^2 = 0.05$, indicating that groups differed in responses for Self and Other conditions, an Agency × Magnitude × Probability interaction, $F(2,79) = 3.99$, $p = 0.005$, $\eta_p^2 = 0.06$, and a main effect of Agency, $F(2,79) = 33.25$, $p < 0.0001$, $\eta_p^2 = 0.29$, reflecting a greater percentage of hard task choices in the Self relative to the Other condition across groups. Not surprisingly, there was a main effect of Magnitude, with higher magnitude levels associated with more hard task choices across groups, $F(2,79) = 47.83$, $p < 0.0001$, $\eta_p^2 = 0.47$, as well as a main effect of Probability, with higher probability levels associated with more hard task choices, $F(2,79) = 60.25$, $p < 0.0001$, $\eta_p^2 = 0.53$, across groups. All other main effects and interactions were not statistically significant.

Follow-Up Analyses

Results for follow-up between-group analyses are presented in Table 3 revealing several group differences in effort-based decision-making across Probability and Magnitude for both Self and Other. Results for within-group analyses are included in Table 4 and reveal differences between Self and Other effort-based decision-making within the ASD and TDC groups. These findings are also depicted in Figs. 2 and 3.

Results revealed group differences in average response times for overall EEfRT performance, $t(81) = 3.28$, $p < 0.01$ (ASD: $M = 4.84$, $SD = 3.88$; TDC: $M = 3.23$, $SD = 1.43$). However, there were no within-group differences between response times when expending effort for Self (ASD: $M = 4.73$, $SD = 3.12$; TDC: $M = 3.28$, $SD = 1.36$) relative to Other (ASD: $M = 4.95$, $SD = 5.68$; TDC: $M = 3.18$, $SD = 1.57$), p's > 0.05.

Correlational Analyses

Correlations explored the relations between EEfRT performance and ASD symptoms as well as affective and reward sensitivities in the ASD group (see Table 5). Correlations were first analyzed separately for reward magnitude and reward probability for the Self and Other conditions. Additional analyses examined the correlation between the proportion of hard task choices for Self and the proportion of hard task choices for Other in the ASD and TDC groups (see Table 6).

Correlations with the EEfRT Self Condition

The proportion of hard task choices selected for Small, Medium, and Large magnitudes were positively correlated with the TEPS consummatory subscale score ($r(50) = 0.35$, $p = 0.01$, $r(50) = 0.29$, $p = 0.04$, and $r(50) = 0.29$, $p = 0.04$, respectively), with increasing levels of consummatory pleasure associated with an increased proportion of hard task selection (see Fig. 4). The proportion of hard task choices selected for Low and High probabilities were positively correlated with the TEPS consummatory subscale score ($r(50) = 0.32$, $p = 0.025$ and $r(50) = 0.39$, $p = 0.005$, respectively), with increasing levels of consummatory pleasure associated with an increased proportion of hard task selection (see Fig. 5).

Correlations with the EEfRT Other Condition

The proportion of hard task choices selected for Small, Medium, and Large magnitudes were positively correlated with the TEPS consummatory subscale score ($r(50) = 0.41$, $p = 0.004$, $r(50) = 0.43$, $p = 0.002$, and $r(50) = 0.39$, p =0 .005, respectively), with increasing levels of consummatory pleasure associated with an increased proportion of hard task selection (see Fig. 6). The proportion of hard task choices selected for Low, Medium, and High probabilities were positively correlated with the TEPS consummatory subscale score ($r(50) = 0.40$, $p = 0.004$, $r(50) = 0.382$, $p = 0.007$, and $r(50) = 0.41$, $p = 0.003$, respectively), with increasing levels of consummatory pleasure associated with an increased proportion of hard task selection (see Fig. 7).

Correlations Between Self and Other EEfRT Conditions

In the ASD group, the proportion of hard task choices selected for Self was positively correlated with the proportion of hard task choices for Other at the Small, Medium, and Large magnitudes ($r(50) = 0.64$, $p < 0.001$, $r(50) = 0.43$, $p = 0.002$, and $r(50) = 0.50$, $p \leq 0.001$, respectively). Additionally, the proportion of hard task choices selected for Self was positively correlated with the proportion of hard task choices for Other at the Low, Medium, and High probabilities ($r(50) = 0.63$, $p < 0.001$, $r(50) = 0.47$, $p < 0.001$, and $r(50) = 0.57$, $p \leq 0.001$, respectively). In the TDC group, the proportion of hard task choices selected for Self was positively correlated with the proportion of hard task choices for Other at the Small magnitude ($r(32) = 0.36$, $p = 0.05$). Additionally, the proportion of hard task choices selected for Self was positively correlated with the proportion of hard task choices for Other at the Low probability ($r(32) = 0.55$, p = 0 .001). These findings are depicted in Table 6.

Discussion

The goal of the present study was to investigate vicarious effort-based decision-making in adolescents with ASD. Contrary to hypotheses, in the standard (i.e., reward for self) condition, adolescents with ASD did not demonstrate a pattern of overall more hard task choices as predicted. Rather, the interaction between Group, Agency, and Magnitude reflected decreased sensitivity to reward magnitude in ASD when making choices to earn rewards for other people. Additionally, the Agency × Group interaction suggested that groups differed in responses for Self and Other. More specifically, in the standard reward condition, adolescents with ASD did not differ in their willingness to expend effort across levels of reward probabilities and magnitudes compared to TDC adolescents. However, when earning rewards for others, the ASD group made significantly more hard task choices relative to the TDC group.

Results indicate that adolescents with ASD are characterized by decreased sensitivity to reward magnitude information when making effort-based decisions specifically in the context of earning rewards for others. This is notable given the literature on altered decision-making in ASD that suggests that individuals with ASD are less likely to use task information and less likely to consider context when making reward choices (De Martino et al. 2008; Johnson et al. 2006). The present study extends this line of research by demonstrating that adolescents with ASD show decreased sensitivity to reward information, specifically reward magnitude, when making choices about working to earn rewards for others.

The observed pattern of altered vicarious effort-based decision-making in ASD may contribute to the social difficulties and lower levels of social competency typically observed in adolescents with ASD (Chevallier et al. 2012; Klin et al. 2002; Orsmond et al. 2004). Typical development of insight into social relationships involves not only an understanding of others' mental states but also an understanding and interest in one's own role in a relationship, an interest which increases during adolescence (Picci & Scherf 2015). The current findings suggest that adolescents with ASD may be less sensitive to relative social information that may contribute to impaired vicarious effort-based decision-making. This impairment may result in decreased willingness to expend effort for another person in the service of developing and maintaining social relationships, though clearly the present study was not designed to test this putative association.

Findings from this study provide support for adolescence as a period when altered effort-based decision-making, particularly in the context of earning rewards for others, is observed in ASD. Whereas typically-developing adolescents tend to show elevated valuation of and heightened behavioral and neural responses to social stimuli and peer interactions as well as increases in other-oriented thoughts compared to self-oriented thoughts (Blakemore 2008; Rilling & Sanfey 2011; Somerville et al. 2010), adolescents with ASD may experience greater decreases in behavioral and neural responses to social rewards and interactions. Adolescents with ASD may not see the social benefit of expending effort for another person and as result, may be particularly unmotivated to earn rewards for others. In this regard, it is noteworthy that the current results from adolescents with ASD did not replicate previous findings in adults with ASD (Damiano et al. 2012), highlighting that it is critical to consider development when examining effort-based decision-making in ASD. Further, future studies examining effort-based decision-making in different age groups are needed to determine if the present results indicate an adolescent-specific effect.

Notably, in the ASD group, there was a significant relation between the proportion of hard task choices for Self and Other across reward parameters (see Table 6). When considered alongside the observed decreased sensitivity to reward magnitude in the Other condition in the ASD group, results suggest that ASD may be characterized by differential sensitivity to changes in vicarious reward magnitude rather than an overall insensitivity to vicarious reward. Results also revealed a positive relation between consummatory pleasure, measured by the TEPS, and the proportion of hard task choices across both Self and Other conditions in the ASD group. High consummatory pleasure, or enjoyment upon obtaining a reward, was associated with a greater proportion of hard task choices when earning rewards for themselves and for others. This finding in the TDC group is consistent with prior observations that nonclinical samples experience pleasure when others win rewards (Braams et al. 2014) and extends this relation to individuals with ASD.

Previous research has demonstrated that individuals with ASD show reduced sensitivity to others' rewards. More specifically, studies examining neural responses to others' rewards have demonstrated hypoactivation in the ACC, a region shown to be involved in processing social information more broadly as well as reward-related information for other individuals (Balsters et al. 2017; De Martino et al. 2008; Lockwood 2016; Lockwood et al. 2015). Further, given that predicting reward outcomes also depends on probability, atypical effort expenditure for vicarious rewards may arise due to atypical computation of socially-specific prediction errors. A common trait of individuals with ASD is intolerance of uncertainty or unpredictability, particularly in social contexts, which may reflect underlying impairment in predictive abilities (Sinha et al. 2014). Notably, aberrant neural responses to social prediction errors have been observed in individuals with ASD relative to controls (Balsters et al. 2017). Therefore, unexpected rewards in the context of others may be processed differently in individuals with ASD.

Groups differed on IQ and gender ratios and these factors altered findings when included as covariates (see Online Resource 1). The current study also included only high-functioning individuals with ASD, and the majority of individuals in the ASD group had a least one comorbidity. This design choice resulted in a sample that is representative of how ASD presents in the community (Mazefsky et al. 2012). However, future studies should further explore the impact of comorbidities on effort-based decision-making in ASD. Further, we did not screen for subtle motor impairments, and given that we observed group differences in response times, we cannot rule out the potential impact of these impairments on EEfRT performance. We also note that GEE analyses (see Online Resource 3) did not replicate the group findings observed with ANOVA results, highlighting the need to replicate the current findings.

Also noteworthy is that the MINI and MINI-KIP-P have yet to be validated in ASD; however, there is no gold standard tool to assess comorbid diagnoses in ASD. Previous studies have used the Kiddie Schedule for Affective Disorders and Schizophrenia (K-SADS; Leyfer et al. 2006) and the Autism Comorbidity Interview-Present and Lifetime Version (ACI; Mazefsky et al. 2012); however, the K-SADS has not been validated in ASD and the ACI is still under development. The goal of the current study was to use the same instrument across all participants while considering participant burden and therefore, the MINI and the

MINI-KID-P were chosen because they are brief and have concordant validity with the K-SADS (Sheehan et al. 2010).

It is important to consider that, whereas the EEfRT measures effort expenditure, there may be other mechanisms that influence EEfRT performance. Specifically, given that the duration of the effort period was dependent on the level of difficulty chosen by participants, decision-making on the EEfRT may be impacted by temporal discounting of rewards rather than effort cost (Apps & Ramnani 2014; Kable & Glimcher 2007). Though button press tasks have been shown to be effortful (Apps & Ramnani 2014; Croxson et al. 2009), it is beyond the scope of the EEfRT to distinguish between effort expenditure and temporal discounting. Additionally, task difficulty and subsequent increases in physical and/or cognitive effort can change the subjective value of rewards (Apps et al. 2015; Kool & Botvinick 2013; Schmidt et al. 2012). Thus, effort itself may alter reward value in the EEfRT.

In summary, the current findings provide evidence for altered vicarious effort-based decision-making in adolescents with ASD. The ASD group was less influenced by increasing reward magnitudes and showed a decreased sensitivity to reward parameters when earning rewards for others, a pattern that may be related to a decreased capacity to derive pleasure from earning rewards for others. Effort-based decision-making provides a window into the behavioral output of the mesolimbic dopamine system that mediates behaviors related to reward processing (Treadway et al. 2009; Treadway & Zald 2011), and as such provides a laboratory-based measure of sensitivity to various reward parameters. The finding of decreased sensitivity to such parameters in the context of vicarious effort-based decision-making in ASD provides an important validation of one aspect of the social motivation hypothesis of autism, namely that certain reward-related behaviors in ASD may be differentially impaired in social relative to non-social contexts. Although this contextual specificity has largely been implicitly assumed, it is not always empirically tested (for exceptions, see, e.g., Chevallier et al. 2014; Peterson et al. 2013). Additionally, differences in patterns of non-vicarious condition results between the present study with adolescents with ASD and prior results from adults with ASD (Damiano et al. 2012) highlight that development is a critical moderating factor for any study that addresses reward processing in ASD (Wolff & Piven 2014). By sampling from a large age range, future studies may accurately pinpoint critical developmental windows when different aspects of reward processing in ASD deviate from trajectories of typically developing individuals, therefore providing insights into optimal windows for intervention efforts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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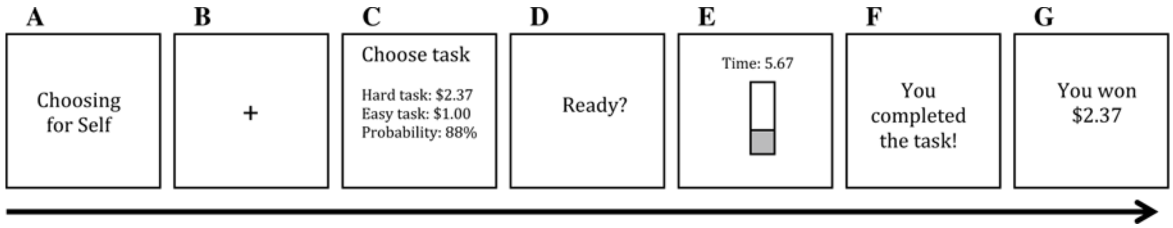

Fig. 1.

Schematic diagram of a single trial of the modified version of the Effort Expenditure for Rewards Task (EEfRT): **a** Participants were told whether they were "Choosing for Self" or "Choosing for Other." **b** Participants were shown a 1 s fixation cue. **c** Unlimited choice period in which participants were presented with information regarding the reward magnitude of the hard task for that trial, and the probability of receiving any reward for that trial. **d** One-second "ready" screen. **e** Participants made rapid button presses to complete the chosen task for 7 s (easy task) or 21 s (hard task). **f** Participants received feedback on whether they completed the task. **g** Participants received reward feedback indicating whether and how much reward they received for that trial

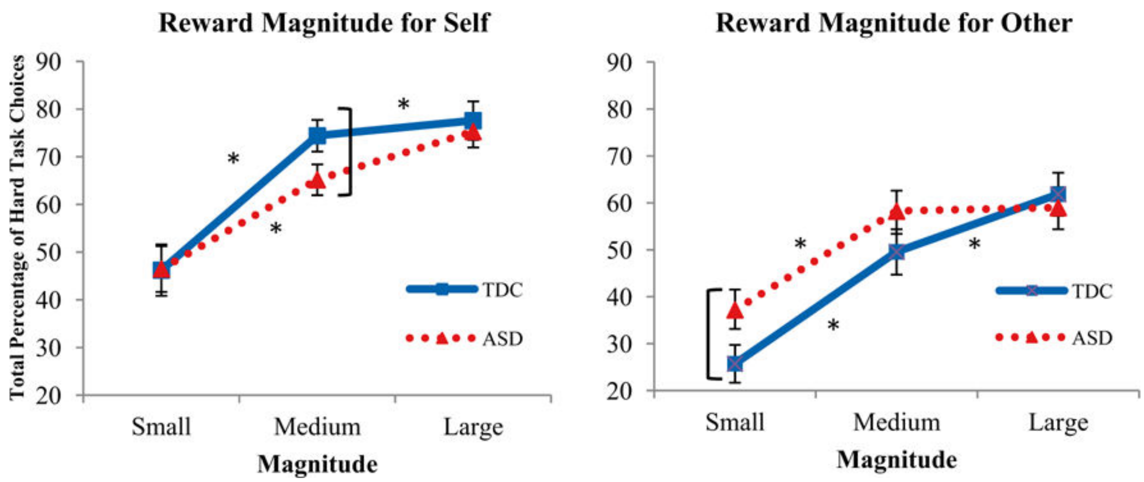

Fig. 2.

The influence of reward magnitude on the percentage of hard task choices for Self (*left*) and Other (*right*). *Asterisks* reflect significant within-group, between-condition effects ($p < 0.05$). *Brackets* indicate significant between-group, within-condition effects ($p < 0.05$)

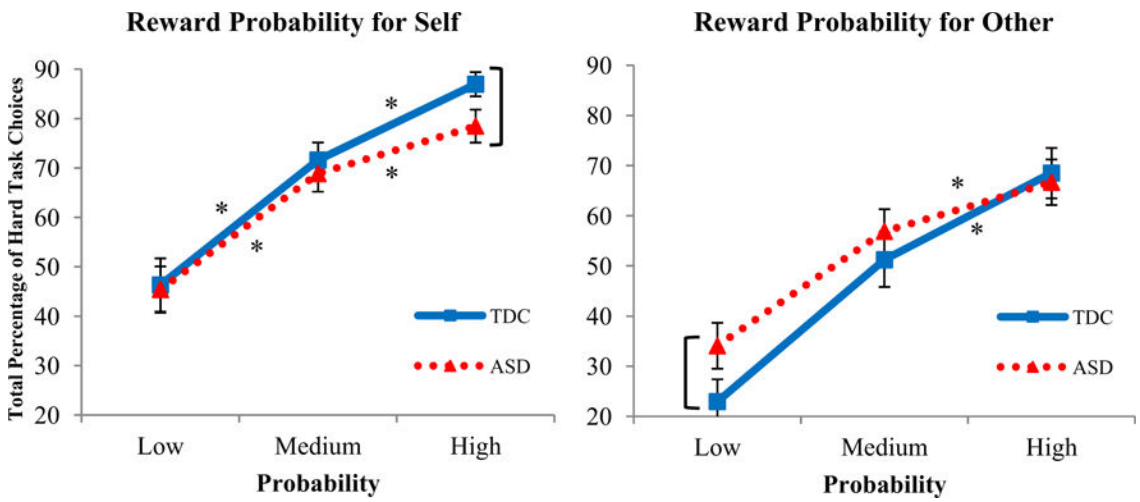

Fig. 3.

The influence of reward probability on the percentage of hard task choices for Self (*left*) and Other (*right*). *Asterisks* reflect significant within-group, between-condition effects ($p < 0.05$). *Brackets* indicate significant between-group, within-condition effects ($p < 0.05$)

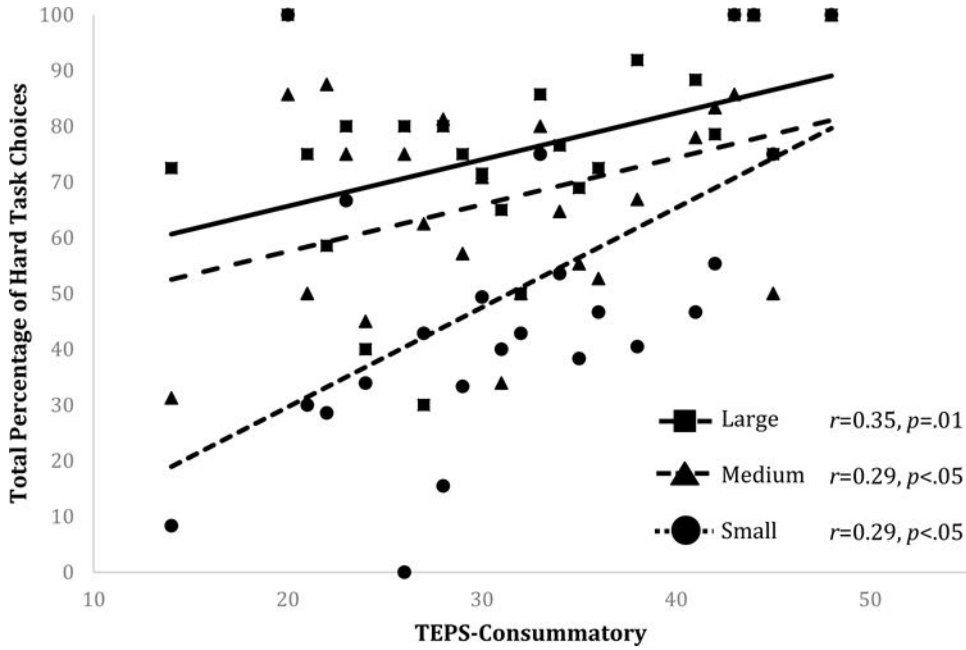

Fig. 4.

Correlations between TEPS-C and the percentage of hard task choices for oneself for the Small, Medium, and Large reward magnitude conditions

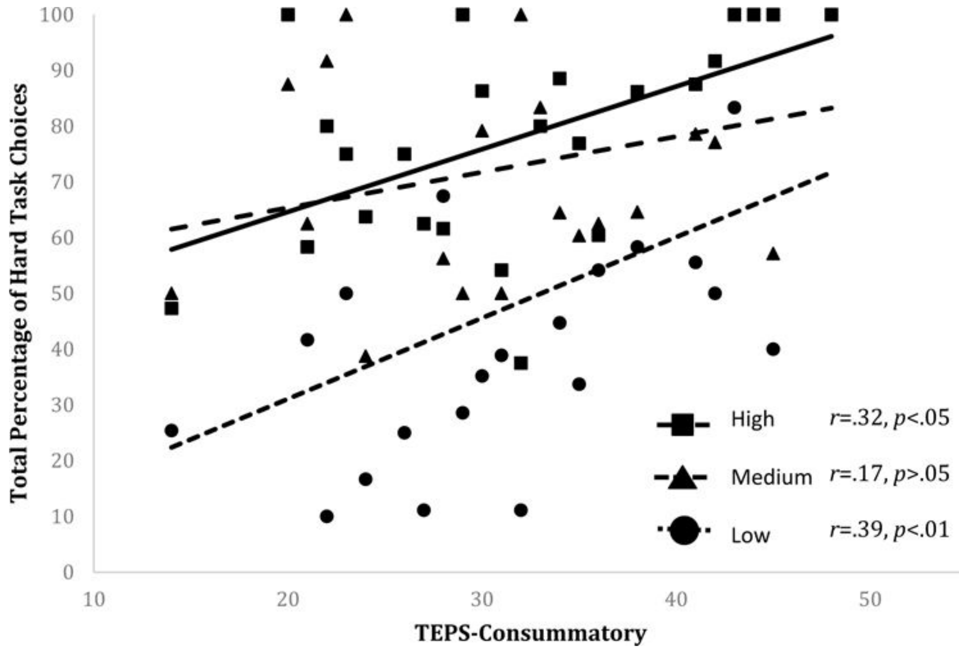

Fig. 5.

Correlations with TEPS-C and the percentage of hard task choices for oneself for the Low, Medium, and High reward probability conditions

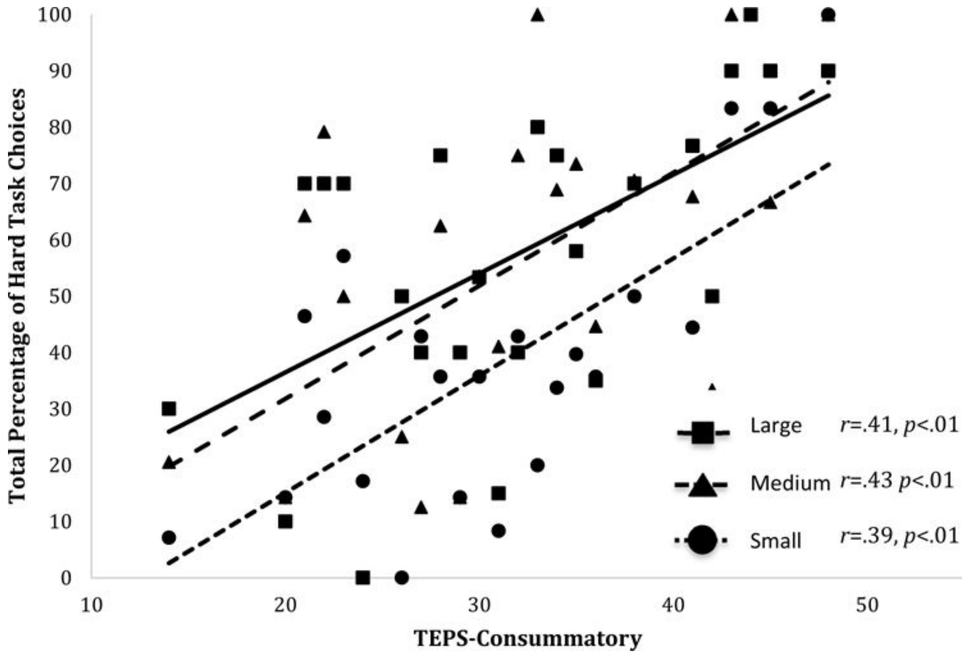

Fig. 6.
Correlations between TEPS-C and the percentage of hard task choices for another person for the Small, Medium, and Large reward magnitude conditions

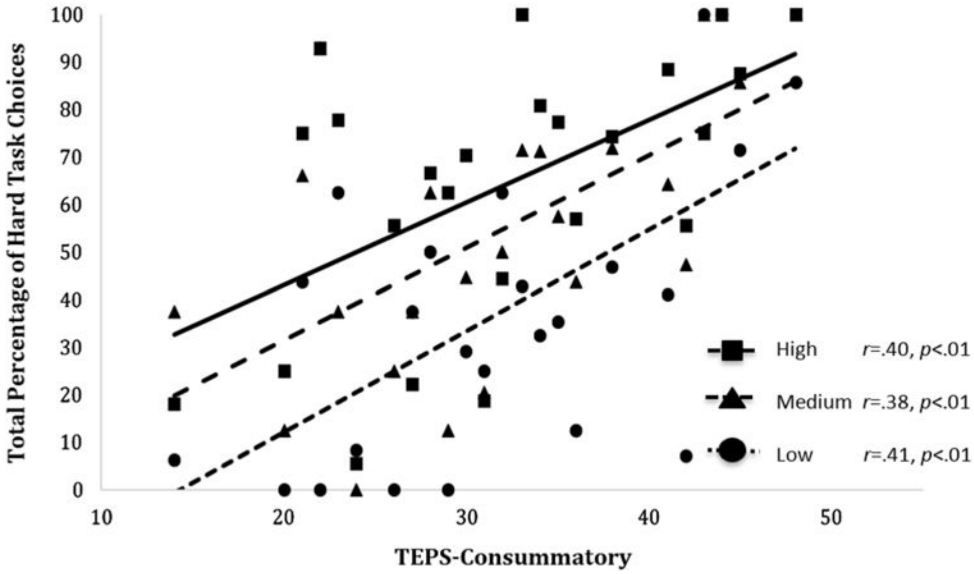

Fig. 7.

Correlations with TEPS-C and the percentage of hard task choices for another person for the Low, Medium, and High reward probability conditions

Table 1

Means (Standard Deviations) for demographic and clinical measures for the ASD and TDC Groups

	ASD (n = 50) Mean (SD)	TDC (n = 32) Mean (SD)	*p* Value
Age	16.02 (2.58)	15.63 (2.95)	0.53
Verbal IQ (VIQ)	104.10 (17.17)	111.80 (11.42)	0.02 *
Performance IQ (PIQ)	101.10 (16.29)	106.10 (10.70)	0.09
Full scale IQ (FSIQ)	102.94 (16.89)	110.38 (11.46)	0.02 *
Male: female ratio	22:3	9:7	< 0.01 [a]
ADOS SA	11.17 (3.52)	NA	
ADOS RRB	3.83 (1.66)	NA	

ADOS SA Autism Diagnostic Observation Schedule, Social Affect domain; *ADOS RRB* ADOS Restricted and Repetitive Behaviors domain

* $p < 0.05$

[a] Pearson's χ^2 p value

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Table 2

Means (Standard Deviations) for symptom and dimensional measures in the ASD and TDC Groups

	n	ASD Mean (SD)	TDC Mean (SD)	*p* Value
SRS *t* score	82	77.36 (9.49)	49.84 (10.29)	<0.0001**
CDI/BDI	53/29	24.94 (2.32)/7.89 (6.54)	26.11 (2.43)/4.40 (4.95)	0.10/0.15
SPSRQ-reward	79	31.43 (11.23)	30.70 (8.90)	0.76
TEPS-anticipatory	82	42.96 (7.85)	45.84 (6.21)	0.08
TEPS-consummatory	82	32.36 (7.75)	36.44 (7.28)	0.02*

* $p < 0.05$;

** $p < 0.01$

Table 3

Follow-up Between-Group *t*-tests for Self and Other conditions of the EEfRT

Self	**Magnitude**	**ASD–TDC *t*(*p*)**	**Cohen's *d***
	Small	0.03 (0.98)	0.01
	Medium	*1.91 (0.06)	0.44
	Large	0.44 (0.66)	0.10
	Probability		
	Low	0.13 (0.90)	0.03
	Medium	0.51 (0.61)	0.12
	High	**2.04 (0.04)	0.44
Other	Magnitude	ASD–TDC *t*(*p*)	Cohen's *d*
	Small	*1.81 (0.07)	0.42
	Medium	1.30 (0.20)	0.30
	Large	0.43 (0.67)	0.10
	Probability		
	Low	1.65 (0.10)	0.38
	Medium	0.81 (0.42)	0.18
	High	0.26 (0.79)	0.06

* $p < 0.10$;

** $p < 0.05$

Table 4

Follow-up Within-Group *t* tests in the ASD and TDC groups for the EEfRT

Self-other	**Magnitude**	**ASD *t*(*p*)**	**Cohen's *d***
	Small	*2.37 (0.02)	0.29
	Medium	1.66 (0.10)	0.25
	Large	***4.14 (0.0001)	0.60
	Probability		
	Low	**2.82 (0.007)	0.37
	Medium	**2.84 (0.007)	0.42
	High	**3.09 (0.003)	0.42
Self-other	Magnitude	TDC *t*(*p*)	Cohen's *d*
	Small	***3.76 (0.0007)	0.76
	Medium	***5.00 (<0.0001)	1.06
	Large	**2.95 (0.006)	0.64
	Probability		
	Low	***4.91 (<0.0001)	0.84
	Medium	***3.69 (0.0008)	0.79
	High	**3.64 (0.001)	0.82
Self	Magnitude	ASD *t*(*p*)	Cohen's *d*
	Small–medium	***4.75 (<0.0001)	0.65
	Medium–large	**3.42 (0.001)	0.44
	Probability		
	Low–medium	***5.28 (<0.0001)	0.79
	Medium–high	*2.66 (0.01)	0.39
Other	Magnitude	ASD *t*(*p*)	Cohen's *d*
	Small–medium	***4.86 (<0.0001)	0.68
	Medium–large	0.26 (0.80)	0.02
	Probability		
	Low–medium	***5.16 (<0.0001)	0.72
	Medium–high	**3.17 (0.003)	0.31
Self	Magnitude	TDC *t*(*p*)	Cohen's *d*

Self-other	Magnitude	ASD *t*(*p*)	Cohen's *d*
	Small–medium	***5.43 (<0.0001)	1.12
	Medium–large	0.81 (0.42)	0.15
	Probability		
	Low–medium	***5.25 (<0.0001)	0.98
	Medium–high	***4.92 (<0.0001)	0.89
Other	Magnitude	TDC *t*(*p*)	Cohen's *d*
	Small–medium	***6.01 (<0.0001)	0.95
	Medium–large	***4.23 (0.0002)	0.46
	Probability		
	Low–medium	***5.69 (<0.0001)	1.01
	Medium–high	***4.11 (0.0003)	0.59

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$

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Table 5

Correlations between the proportion of hard task choices on the EEfRT and questionnaire measures in the ASD group

Variables	Proportion hard task choices for self						Proportion hard task choices for other					
	Reward magnitude			Reward probability			Reward magnitude			Reward probability		
	Small	Medium	Large	12%	50%	88%	Small	Medium	Large	12%	50%	88%
SRS	−0.01	0.05	0.07	−0.03	0.09	0.08	−0.02	0.02	−0.02	−0.14	0.07	0.05
CDI	−0.01	0.02	0.07	−0.33	0.31	0.24	0.20	0.30	0.16	−0.10	0.33	0.31
BDI	−0.17	0.17	−0.35	−0.22	−0.08	−0.15	−0.23	−0.01	0.05	−0.38	0.20	0.16
SPSRQ-R	0.04	−0.18	−0.06	−0.11	−0.22	−0.24	0.02	−0.10	−0.26	−0.20	−0.15	−0.04
TEPS-A	0.10	0.09	0.13	0.20	0.00	0.04	−0.03	−0.06	−0.02	0.05	−0.06	−0.08
TEPS-C	0.35**	0.29*	0.29*	0.32*	0.17	0.39**	0.41**	0.43**	0.39**	0.40**	0.38**	0.41**

* $p < 0.05$;

** $p < 0.01$

Table 6

Correlations between the proportion of hard task choices on the EEfRT for Self and Other in the ASD and TDC groups

Group	Reward magnitude			Reward probability		
	Small	Medium	Large	12%	50%	88%
ASD	0.64***	0.43**	0.50***	0.63***	0.47***	0.57***
TDC	0.36*	0.30	0.24	0.55**	0.30	0.23
p Value	0.11	0.52	0.20	0.60	0.40	0.08

* $p < 0.05$;

** $p < 0.01$;

*** $p < 0.001$,