The Impact of Depression on Motivated Behavior in Autism Spectrum Disorder

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Abstract

Though Autism Spectrum Disorder (ASD) and Major Depressive Disorder (MDD) are distinct disorders, they have both been shown to present with reward processing deficits. Specifically, both disorders are characterized by decreased anticipation of rewarding stimuli. Because there is a 43% comorbidity rate of MDD in ASD, the present study examined the relation of depressive symptoms and hedonic capacity with effort-based decision-making in adolescents with ASD. We utilized a sample of 49 adolescents with high-functioning ASD garnered from a larger study in the laboratory. Depressive symptoms were measured with the Mini International Neuropsychiatric Review (MINI), the Child Depression Inventory (CDI), and Beck Depression Inventory (BDI). The Temporal Experience of Pleasure Scale (TEPS) was used to measure hedonic capacity, and the Effort Expenditure for Rewards Task (EEfRT) was used to measure effort-based decision-making. Results showed significant relations between dimensional measures of depressive symptoms and hedonic capacity with effort-based decision-making, but no significant relations between categorical diagnoses of MDD and effort-based decision-making. These results suggest that depressive symptoms, specifically anhedonia, and hedonic capacity should be considered as important explanatory mechanisms for the impaired reward processing seen in ASD.

Keywords: Autism Spectrum Disorder, Major Depressive Disorder, comorbidity, effort-based decision-making, hedonic capacity

The Impact of Depression on Motivated Behavior in Autism Spectrum Disorder

There has been recent emphasis on understanding the contribution of reward processing deficits to core autism spectrum disorder (ASD) symptoms. It is well documented that individuals with ASD present with impaired socio-communicative skills (American Psychiatric Association, 2013). In an effort to explain the mechanisms behind these deficits, the "social motivation hypothesis of autism" suggests that individuals with ASD may derive or anticipate less pleasure (reward) from social stimuli than do neurotypical individuals. This would result in decreased motivation to cultivate social skills, and subsequently, the deficits seen later in life.

This theory considers ASD as an isolated disorder, though it often presents as comorbid with one or more other psychological disorders. Specifically, it has a 43% comorbidity rate with Major Depressive Disorder (MDD, Sterling et. al., 2008). One of MDD's core symptoms is anhedonia, which is defined as a loss of pleasure in previously enjoyed activities (American Psychiatric Association, 2013). This means MDD presents with the same altered reward processing suggested by the social motivation hypothesis of autism. Consequently, we must ask if the reward processing deficits in ASD are due to ASD or MDD symptomology.

As such, the present study asks if anhedonia contributes to reward processing deficits in a sample of adolescents with high-functioning ASD (HFA). Anhedonia will be measured in 3 ways: Diagnosis of MDD, severity of depressive symptoms, and hedonic capacity. Ultimately, we aim to determine whether comorbid depression, and specifically the symptom of anhedonia, plays a role in reward-processing deficits seen in HFA.

Autism Spectrum Disorder (ASD)

Autism spectrum disorder (ASD) is classified by the DSM-V (American Psychiatric Association, 2013) as a neurodevelopmental disorder characterized by symptoms in in two broad

domains: (1) social interaction and communication impairments and (2) restricted and repetitive patterns of behavior, interests, or activities (RRBs). In order to receive a diagnosis of ASD, an individual must present with (1) deficits in social communication and social interaction across multiple contexts and (2) at least two manifestations of RRBs. Additionally, symptoms must have been present in the early developmental period and cause clinically significant impairment in social, occupational, or other important areas of functioning. In adolescents with ASD, social communication deficits are characterized by unusual eye contact, impaired expressive language, lack of insight, and decreased quality and quantity of social overtures (Lord et. al., 2000). In other words, adolescents with ASD make fewer attempts to socially interact with others than their typically developing peers, and the social overtures they do make may come across as odd, immature, or inappropriate.

A potential explanation for the social communication and interaction impairments seen ASD was recently posited by Chevallier and colleagues (2012) who considered the role of motivational factors. The "social motivation hypothesis of autism" suggests that an early deficit in social motivation may contribute to the later social deficits. Most importantly, this theory suggests that while social interaction has an intrinsic motivational value in typically developing adolescents, this value is diminished in individuals with ASD. This means that those with ASD may demonstrate decreased pleasure ("reward liking") or decreased reward anticipation ("reward wanting") in the presence of social stimuli or while performing prosocial behavior.

Major Depressive Disorder

Impaired reward liking and wanting are also seen in Major Depressive Disorder (MDD), a disorder commonly diagnosed as comorbid with ASD. However, in MDD these impairments are not specific to social stimuli and behavior. MDD is classified by the DSM-V (American

Psychiatric Association, 2013) as a change from an individual's previous functioning for at least two consecutive weeks, during which time an individual experiences either a depressed mood or loss of interest or pleasure ("anhedonia"). Research has shown evidence for impaired reward liking in MDD (Whitton, Treadway, and Pizzagalli, 2015). More recently, researchers have explored the impact of motivational factors on reward processing in individuals with MDD and found marked reward-based decision-making impairments, such that those with MDD are less sensitive to increases in reward than typical controls (Treadway et al., 2012). Further, individuals with MDD often exhibit a decreased ability to use reward cues to modulate motivational behavior as compared to typical controls (Whitton et al., 2015). These conclusions were supported through neuroimaging studies with the observation of decreased putamen activation in response to reward anticipation.

MDD can be measured both categorically and dimensionally. A categorical diagnosis of MDD is dichotomous: a patient will either meet criteria for the diagnosis or they will not. The categorical measure of MDD used in this study was the Mini International Neuropsychiatric Interview (MINI). The MINI is derived from the Structured Clinical Interview for DSM Disorders (SCID) and is a reliable method to diagnose DSM disorders (Sheehan et. al., 1998). The MINI is parent-reported for individuals younger than age 18, and self-reported for individuals ages 18 and over. Dimensional measures of MDD are continuous measures of depression symptom severity. The dimensional measures of MDD used in this study were the Child Depression Inventory (CDI; Helsel & Matson, 1984) for individuals under age 18 and the Beck Depression Inventory (BDI; Beck, Steer, Ball, & Ranieri, 1996) for individuals aged 18 and over.

Comorbidity of MDD in ASD

The overlap in reward processing deficits between MDD and ASD in accompaniment with the high comorbidity rate calls into question whether MDD symptoms contribute to the social motivation impairments seen in ASD. Approximately 70% of individuals diagnosed with ASD meet criteria for at least one other psychiatric disorder (Mazefsky et. al., 2012). Additionally, Sterling and colleagues (2008) found that nearly 43% of individuals diagnosed with ASD also met criteria for MDD. This study also found that within the ASD population, individuals with relatively high cognitive ability and low social impairment were most likely to endorse depressive symptoms. These symptoms are likely the result of an awareness of their struggles in social settings and that peers treat them differently from others (Sterling et al., 2008).

Further, there may be overlap between the underlying mechanisms of reward processing in ASD and MDD. As noted previously, both disorders present with a deficit in reward liking (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Whitton et al., 2015). Whitton and colleagues (2015) noted that the reward-liking deficit in MDD could be attributed to reduced activity in the mesolimbic dopamine system (reward network of the brain), primarily in the ventral striatum. A similar deficit in ventral striatum activation was found in individuals with ASD during monetary reward anticipation (Delmonte et. al., 2012).

Effort-Based Decision-Making

To directly examine motivational behavior, Treadway and colleagues (2009) created an effort-based decision-making task. Previous studies have shown that most organisms abide by the "law of least effort," which states that they will exert the least amount of effort possible to gain a reward (Salamone, 2006; Solomon, 1948). However, as a reward increases, in either probability or magnitude, individuals will be willing to exert more effort to obtain the reward. Treadway's task, the Effort Expenditure for Rewards Task (EEfRT), aims to measure sensitvity

to changing reward parameters (probaiblity and magnitude). This task was initially used to measure motivated behavior in adults with anhedonia and with frank MDD (Treadway et al., 2009; Treadway et al., 2012). Results revealed that both groups made fewer hard task choices for larger but uncertain rewards relative to the control groups. In other words, as the reward magnitude and probaiblity of winning a reward fluctuated, willingness to expend effort on the task did not fluctuate accordingly. However, both the anhedonia and MDD groups showed a positive correlation between reward parameter flucutation and percentage of hard task/high reward choices, demonstrating sensitivty to changing reward parameters.

Effort-based Decision Making in ASD

Our research group has conducted two previous studies using the EEfRT in individuals with ASD. The first was conducted on adults with high functioning ASD, and the latter on adolescents with high functioning ASD (Damiano et al., 2012; Mosner et. al., 2016). Damiano et al. (2012) found that HFA adults showed decreased sensitivity to fluctuating reward parameters and chose more hard-task choices overall relative to the control group. This finding is in line with results from Treadway et al (2009; 2012), supporting the claim that both adults with ASD and adults with MDD display altered motivated behavior. However, contrary to on the findings of Damiano et al. (2012) in adults with ASD, adolescents with ASD did not differ significantly from the control group when earning rewards from themselves (Mosner et. al., 2016).

The Current Study:

As previously stated, MDD and anhedonia impact effort-based decision-making (Treadway et al., 2009; Treadway et al., 2012), and MDD is likely the most common comorbid psychiatric disorder in ASD (Ghaziuddin, Ghaziuddin, & Greden, 2002). Our research group recently reported different profiles of effort-based decision-making in adolescents with ASD on

the EEfRT (Mosner et. al., 2016). The goal of the current study was to explore whether depressive symptoms and/or hedonic capacity were related to patterns of motivated behavior in adolescents with ASD. Based on the findings of Treadway et al. (2009) that anhedonia biases people to make more easy-task choices, we hypothesized the following:

1) We hypothesize that as the severity of depressive symptoms increases, sensitivity to increasing reward parameters will decrease in adolescents with ASD. This will be tested by correlating CDI/BDI composite z-scores with difference in percentage of EEfRT hard task choices. Additionally, we hypothesize that increased severity of depressive symptoms will correlate with decreased motivated behaviors when a greater reward or chance of reward is available. This will be tested by correlating CDI/BDI composite z-scores with percentage of hard task choices on individual EEfRT levels.
2) We hypothesize that participants with ASD who meet criteria for a categorical diagnosis of MDD will show decreased sensitivity to increasing reward parameters compared to those with ASD who do not meet criteria for that diagnosis. This will be tested by running a multivariate ANOVA on MINI diagnoses and difference in percentage of EEfRT hard task choices. Additionally, we hypothesize that those without MDD will exhibit greater motivated behaviors than those with MDD when a greater reward or chance of reward is available. This will be tested by running a multivariate ANOVA on MINI diagnoses and percentage of hard task choices on individual EEfRT levels.
3) We hypothesize that those with ASD with greater hedonic capacity, as measured by the temporal experience of pleasure scale (TEPS; Gard, Gard, Kring, & John, 2006),

will show increased sensitivity to increasing reward parameters compared to those with ASD who have smaller hedonic capacity. This will be tested by correlating TEPS scores with difference in percentage of EEfRT hard task choices. Additionally, we hypothesize that greater hedonic capacity will correlate with greater motivated behaviors when a greater reward or chance of reward is available. This will be tested by correlating TEPS scores with percentage of hard task choices on individual EEfRT levels.

Methods

The biomedical institutional review board at University of North Carolina (UNC) at Chapel Hill approved this study.

Participants

This project is part of a larger study that has been completed by Maya Mosner, M.A., a 4th year doctoral student in Dr. Gabriel Dichter's research laboratory. As such, the sample used in this project is nearly identical to that of her master's thesis (Mosner et al., 2016). However, this project only uses the subjects with ASD from her study. Forty-nine individuals with ASD (age M=15.98, SD=2.59) ages 12-20 participated in this project. Participants with ASD were recruited through the UNC Autism Research Registry, a resource at the Carolina Institute for Developmental Disabilities (CIDD).

Individuals with ASD were high functioning, defined as having fluent phrase speech and an IQ greater than 70. They were required to have neither sensory abnormalities nor a diagnosis of intellectual disability. The group was 90% (N = 44) male and 10% (N = 5) female. The group's race and ethnicity breakdown was 90% Caucasian, 4 African American, 1 Hispanic (Table 1). Twenty-nine percent of adolescents with ASD met criteria for MDD.

Procedure

Prior to participation, consent was obtained for participants over age 18, and assent was obtained for those below age 18. Following consent, participants were administered the EEfRT as well as cognitive, diagnostic, and symptom assessments. Both the EEfRT and symptom assessments were administered on a computer, the former using MatLab software, and the latter using Qualtrics surveys. Participants were reimbursed at a base rate of $10.00, with an additional $10.00 per hour during the testing session, and an additional $2.00-$8.66 earned during the EEfRT task.

Materials and Measures

Effort-Based Decision-Making Task.

As a measure of motivation, participants completed the effort-based decision-making task (EEfRT) that was developed by Treadway and colleagues (2009). In this computer-based measure, participants chose to complete either an "easy task" or "hard task" on each trial. For both the easy and hard task, participants worked to fill a virtual bar within a given amount of time by repeatedly pressing a key on the keyboard. The easy task required participants to press a key with their dominant pointer finger 30 times in 7 seconds, while the hard task required them to press a key with their recessive pinky finger 100 times in 30 seconds.

As noted previously, the EEfRT measures effort-based decision-making by examining how much effort participants are willing to expend at varying reward magnitudes and probabilities. Reward magnitudes varied as follows: for the easy task, they were eligible to win $1.00; e for the hard task, they could win anywhere from $1.24 to $4.12. We defined "small reward magnitude" as $1.24-$2.00, "medium reward magnitude" as $2.01-$3.00, and "high reward magnitude" as $3.01-$4.12.

Additionally, each time participants successfully completed a trial, they were not guaranteed to win money. As such, they were also shown the probability of obtaining the reward (reward probability): high reward probability (88%), medium (50%), and low (12%). There were equal proportions of each probability level across the experiment, and each level of probability appeared once along with each level of reward magnitude (Treadway et al., 2009). Trials types (varying in reward magnitude and reward probability) 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). Finally, participants were informed that at the end of the measure, the computer would randomly choose two occurrences where they earned money, and that would be the money they actually received for playing the task.

Each trial proceeded as follows: First, participants saw a screen that informed them of the reward magnitude for the easy task and the hard task as well as the probability of earning a reward if they successfully completed the trial in the time limit. After the participants selected a task, the computer asked if they were ready. Once participants indicated that they were ready (pressed the space bar) the task began. After the timer ran out, the computer either told participants "you successfully completed that task" or "you have failed to complete the task." If the task was successfully completed, the computer indicated that participants earned "no money this trial" or "you have won [$X.XX] this trial." Then, the next trial would begin, and the cycle would repeat.

Cognitive Assessments

An IQ test was administered to assess participants' verbal, performance, and full scale IQ. The Wechsler Abbreviated Scale of Intelligence (WASI) was used for participants ages 18-20, while the Kaufman Brief Intelligence Test, Second Edition (KBIT-II) was used for participants

ages 12-17. Both tests are in accordance with their unabbreviated counterparts (WASI; Axelrod, 2002; KABC-II; Kaufman & Kaufman, 2004) and both measures have been previously used in ASD samples (Bardikoff & McGonigle-Chalmers, 2014; Dichter, Damiano, et al., 2012).

Diagnostic Assessments

All participants in the ASD group were administered the Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord et. al., 2012) to confirm ASD diagnoses. This is a semi-structured interview with activities designed to assess for current ASD symptoms. A research reliable clinician administered each ADOS, and standard ASD algorithm cutoffs were used.

Participants were administered either the Mini International Neuropsychiatric Interview (MINI; ages 18-20) or a child version of the MIIN, the MINI-KID-P, (ages 12-17) to assess for past or current Axis-I psychopathology (Sheehan et al., 1998; Sheehan et al., 2010). These are semi-structured interviews that are administered with the participant or caregiver of the participant, respectively. The MINI gives a dichotomous diagnosis for each Axis I disorder - either participants meet criteria or they do not. As such, for this project, the MINI was used to categorically group participants into those with ("depression present") and without MDD ("depression absent").

Symptom Assessments

The Beck Depression Inventory II (BDI-II) was administered by qualtrics survey to participants ages 18-20 to assess for depression symptom severity (Beck et al., 1996). The Child Depression Inventory (CDI) was administered for participants ages 12-17 (Helsel & Matson, 1984). These measures ask participants to select the most applicable of three (CDI) or four (BDI) statements for each question using a Likert scale, with each statement increasing in symptom

severity. Possible answers for the BDI include “I do not feel sad,” “I feel sad,” “I am sad all the time and can’t snap out of it” and “I am so sad and unhappy that I can’t stand it” (Beck et al., 1996). CDI possible answers are similar, but only include three choices instead of four. The comparable CDI answers include “I am sad once in a while,” “I am sad many times,” and “I am sad all the time.” The CDI and BDI were used as dimensional measures of depressive symptoms. In other words, these assessments allowed us to give participants scores of depression symptom severity, compared to the dichotomous diagnosis determined by the MINI.

The Temporal Experience of Pleasure Scale (TEPS) was administered to all participants as a measure of hedonic capacity (Gard et al., 2006). Participants are asked to rank on an 18-item Likert scale from 1 (*very false for me)* to 6 (*very true for me*) for statements such as “the smell of freshly cut grass is very enjoyable to me” and “a hot cup of coffee or tea on a cold morning is very satisfying to me.” There are two subscales of the TEPS: the anticipatory scale (TEPS-A) is related to reward responsiveness and imagery; and the consummatory pleasure scale (TEPS-C) is related to openness to different experiences and appreciation of positive stimuli.

Participants were administered the Social Responsiveness Scale (SRS), a dimensional self-report measure that examines the severity of social-communicative ASD symptoms as they occur in natural social settings (Constantino et al., 2003). This is a 65-item Likert scale, scored from 0 (*not true*) to 3 (*almost always true*). Raw scores on the SRS can range from 0 to 195. These scores are then converted to t-scores (M=50, SD=10), which are used for clinical evaluation. A t-score of 60 is the accepted clinical cutoff (Wilkinson, 2011). Scored from 60-75 suggest mild or high-functioning ASD, while scores 76 or above suggest severe ASD. Scores below 60 suggest an absence of ASD symptoms. These scores were used to control for the

possibility of ASD symptoms influencing correlations between MDD/depressive symptoms and EEfRT performance.

Results

The current study examined the impact of MDD diagnoses, severity of depressive symptoms, and hedonic capacity on reward motivation in the context of ASD. Motivation was measured by effort-based decision-making on the EEfRT. Given that this is a pilot study, we did not correct for multiple comparisons.

Impact of MDD on motivation in ASD

The impact of MDD on motivation was addressed by examining the relation between MDD diagnoses, assessed via the MINI, and EEfRT performance. Measures of EEfRT performance included percent hard task choices at high, medium and low reward magnitude and probability levels as well as sensitivity to reward parameter, defined as the difference in percent hard task choices between the three different reward levels.

To investigate relations between MDD status and EEfRT reward magnitude on EEfRT hard task choices, we ran a 2 (Depression Status: Present, Absent) x 3 (EEfRT Magnitude Condition: Large, Medium, Small) multivariate ANOVA on percentage of hard task choices within the ASD sample. Results indicated a main effect of EEfRT, magnitude, multivariate $F(2,43) = 17.10$, $p < 0.0001$, reflecting that individuals with ASD made more hard task choices with higher magnitude levels for successful completion of the task. There was no main effect of Depression Status and no interaction.

Next, to investigate relations between MDD status and EEfRT reward probability on EEfRT hard task choices, we ran a 2 (Depression Status: Present, Absent) x 3 (EEfRT Probability Condition: High, Medium, Low) multivariate ANOVA on percentage of hard task

choices. Results indicated a main effect of EEfRT probability, multivariate $F(2,43) = 23.65$, $p < 0.0001$, reflecting that individuals with ASD made more hard task choices when there was an increased probability of earning a reward upon successful completion of the task.. There was no main effect of Depression Status and no interaction.

We further investigated relations between MDD status and sensitivity to EEfRT reward magnitude by examining difference in percent hard task choices at the three different reward levels. We conducted a 2 (Depression Status: Present, Absent) x 3 (Change in EEfRT Magnitude Condition: Large minus Small; Large minus Medium; Medium minus Small) multivariate ANOVA on percentage of hard task choices. Results indicated a main effect of sensitivity to reward magnitude, multivariate $F(2,43) = 19.46$, $p < 0.0001$, reflecting that more hard task choices were associated with greater differences in reward magnitude. There was no main effect of Depression Status and no interaction.

Finally, we investigated relations between MDD status and sensitivity to EEfRT reward probabilities by examining difference in percent hard task choices between the three different reward levels. We ran a 2 (Depression Status: Present, Absent) x 3 (Change in EEfRT Probability Condition: High Minus Low; High Minus Medium; Medium minus Low) multivariate ANOVA on percentage of hard task choices. Results indicated a main effect of difference in probability of earning rewards, multivariate $F(2,43) = 23.65$, $p < 0.0001$, reflecting that more hard task choices were associated with greater differences in reward probability. There was no main effect of Depression Status and no interaction.

Impact of depression symptom severity on motivation in ASD

The impact of depression symptom severity on reward motivation in ASD was addressed by examining relations between CDI or BDI scores with EEfRT performance. As previously

noted, participants ages 12-17 received the CDI to measure depression symptom severity, while those ages 18-20 received the BDI. Given that the CDI and BDI include different scales (though both measure depressive symptoms), CDI and BDI values were converted into z-scores with a mean of 0 and SD of 1. Thus, depression symptom severity was operationalized as a CDI/BDI composite z-score.

We evaluated correlations between the CDI/BDI composite z-score and percentage of hard task choices in each of the six EEfRT magnitude and probability conditions (i.e. large magnitude, medium magnitude, small magnitude, high probability, medium probability, low probability). A weak negative correlation was found between percent of hard task choices made at low reward probability and depression symptom severity, such that percent of hard task choices decreased as depression symptom severity increased, $r(47) = -0.29$, $p = 0.04$ (see Figure 1). A partial correlation between these measures controlling for ASD symptom severity (as measured by the SRS) was completed, and the correlation remained significant, $r(46) = -0.29$, $p = 0.04$. The remaining five correlations yielded no significant results, p's > 0.05.

Next, we examined correlations between the CDI/BDI composite z-score and sensitivity to changes in EEfRT magnitude and probability conditions (i.e., large minus small magnitudes; large minus medium magnitudes; medium minus small magnitudes and high minus low probabilities; high minus medium probabilities; medium minus low probabilities). A moderate positive correlation was seen between difference in percent of hard task choices made from low to high reward probability and depression symptom severity, such that reward sensitivity increased as depression symptom severity increased, $r(47) = 0.34$, $p = 0.016$ (see Figure 2). A partial correlation between these measures controlling for ASD symptom severity (as measured by the SRS) was completed, and the correlation remained significant, $r(46) = 0.33$, $p = 0.02$. A

moderate positive correlation was also seen between difference in percent of hard task choices made from low to medium reward probability and depression symptom severity, such that reward sensitivity increased as depression symptom severity increased, $r(47) = 0.41$, $p = 0.003$ (see Figure 3). A partial correlation between these measures controlling for ASD symptom severity as measured by the SRS was completed, and the correlation remained significant, $r(46) = 0.40$, $p = 0.004$. The remaining four correlations yielded no significant results, $p > 0.05$.

Impact of hedonic capacity on motivation in ASD

This was analyzed by examining correlations between hedonic capacity, as measured by the TEPS Subscales (TEPS-Anticipatory, TEPS-Consummatory, and TEPS total scores), and percentage of EEfRT hard task choices in each of the six magnitude and probability conditions listed above. A moderate positive correlation was seen between percent of hard task choices made at high reward probability and consummatory hedonic capacity, such those with higher consummatory hedonic capacity were likely to make more hard task choices at a high reward probability, $r(47) = 0.37$, $p = 0.008$ (see Figure 4). A partial correlation between these measures controlling for ASD symptom severity as measured by the SRS was completed, and the correlation remained significant, $r(46) = 0.37$, $p = 0.008$. A moderate positive correlation was also seen between percent of hard task choices made at medium reward magnitude and consummatory hedonic capacity, such that as reward magnitude increased, consummatory hedonic capacity increased, $r(47) = 0.31$, $p = 0.030$ (see Figure 5). A partial correlation between these measures controlling for ASD symptom severity (as measured by the SRS) was completed, and the correlation remained significant, $r(46) = 0.31$, $p = 0.032$. Finally, a moderate positive correlation was seen between percent of hard task choices made at low reward magnitude and consummatory hedonic capacity, such that as reward magnitude increased, consummatory

hedonic capacity increased, $r(47) = 0.34$, $p = 0.016$ (see Figure 6). A partial correlation between these measures controlling for ASD symptom severity as measured by the SRS was completed, and the correlation remained significant, $r(46) = 0.34$, $p = 0.018$. The remaining 15 correlations yielded no significant results, $p's > 0.05$.

Next, we examined correlations between TEPS-A, TEPS-C, and TEPS total scores and sensitivity to changes in EEfRT magnitude and probability conditions, as listed above. These analyses yielded no significant results, $p's > 0.05$.

Discussion

The aim of this study was to examine the effects of comorbid depression on reward processing in adolescents with ASD. We hypothesized that both categorical diagnoses and dimensional measurements of depression would correlate negatively with reward sensitivity, such that those with depression would have less reward sensitivity than those without, and as severity of depressive symptoms increased, reward sensitivity would decrease. Results showed that this was not the case. When diagnosing depression categorically (depression status), no significant relationship was seen between categorical depression diagnosis and reward sensitivity, as measured by the difference in percentage of hard task choices made between conditions. Additionally, no significant relationship was seen between depression status and percentage of hard task choices made in any one condition. The CDI/BDI scores yielded significant results, but with conflicting findings. When comparing severity of depressive symptoms with percentage of hard task choices made in the low reward probability condition, results indicated a negative correlation in which increased symptom severity correlated with blunted motivated behavior, such that the individual makes fewer hard task choices.

This finding is in line with the results from previous literature demonstrating decreased motivated behaviors in individuals with MDD using the EEfRT (Treadway et. al., 2012). It especially makes sense in the low probability condition because it would require more motivation to complete the hard task at low reward probability than in other conditions where the participant was more likely to obtain the reward. However, as reward probability increased, there was a positive correlation between depressive symptom severity and reward sensitivity, such that those with more severe symptoms were more likely to increase their effort when there was a greater probability of reward. This finding is in line with the "law of least effort," which states that individuals will exert the least amount of effort possible to gain a reward (Salamone, 2006; Solomon, 1948), and thus reflects typical reward processing. However, the MDD literature suggests that depressive symptoms, specifically anhedonia, correlate with blunted activity in the mesolimbic dopamine system, and consequently, blunted reward sensitivity. This means that our participants showed typical reward processing results despite the literature suggesting that their results should have been atypical. However, MDD is also correlated with blunted emotional activity. It is possible that, in order to compensate for this deficit, participants chose the task that had a greater immediate reward value to them; that is, they chose the task that more immediately piqued their interest (Must, Szabó, Bódi, Szász, Janka, & Kéri, 2005). As the probability of earning money increased, the choice with more immediate reward value would be that with greater reward magnitude: the hard task. If this were the case, participants with more severe depressive symptoms and TDCs would have similar reward sensitivity results; both would make an increased percentage of hard task choices in response to a greater increase in reward. However, this explanation suggests that while the results would be the same between these groups, the mechanisms behind them would vary. As explained by the law of least effort, TDCs

would be motivated to increase their effort as necessary when there was a greater chance of earning a reward or an opportunity to earn a greater reward. Must et. al.'s (2006) explanation suggests that individuals with severe depressive symptoms would choose the option with the most emotional reward as a compensation for their lack of motivation. Because higher reward magnitudes and probabilities would have greater emotional valence, reward sensitivity results would appear the same in individuals with severe depressive symptoms as TDCs.

Despite the results not aligning with our hypotheses in terms of directionality, it is noteworthy that measuring depression categorically versus dimensionally yielded different results. The dimensional measure of depression yielded significant results in regards to reward sensitivity, while a categorical diagnosis did not. This has clinical implications in that it brings into question the efficacy of the Diagnostic and Statistical Manual of Mental Disorder's (DSM) categorical diagnostic system. Diagnosis of MDD by the MINI is based off the DSM, which requires that an individual must present with at least five MDD symptoms to qualify for the diagnosis. Consequently, for the analyses, anyone with zero to four symptoms of MDD was placed in the "depression absent" group and anyone with five or more symptoms was placed in the "depression present" group. This means people within the same group could have presented very differently, while people between groups could have appeared to be very similar. For example, the reward processing of someone with four symptoms of MDD is likely different from someone with zero symptoms of MDD, but very similar to someone with five symptoms of MDD. Contrastingly, a dimensional measure assessing symptom severity did not create any such categories. This allowed for analyses that showed a relationship between depressive symptoms and reward processing that was not discernable using DSM diagnostic methods.

In addition to examining categorical and dimensional measures of depression, the current study also hypothesized that hedonic capacity would be positively correlated with reward sensitivity. Results indicated that there was no correlation between the TEPS (or either of its subscales) and reward sensitivity, as measured by differences in percentage of hard task choices between levels of EEfRT magnitude and probability conditions. There were positive correlations with the consummatory subscale and high probability reward, medium magnitude reward, and low magnitude reward. This is in line with the previous literature which suggests an increased ability to experience pleasure in response to rewarding stimuli should result in increased motivated behaviors to earn those rewards (Whitton et al., 2015). However, previous research has also found hedonic capacity deficits in MDD and ASD to be related to reward anticipation, rather than reward liking (consummatory pleasure). Contrastingly, these results show no significant results in the way of reward anticipation, but do suggest that individuals with less hedonic capacity are less likely to experience reward in response to stimuli that are rewarding for individuals with typically development, such as money. Previous research supports atypical reward processing in ASD such that individuals with ASD have been found to present with decreased response to monetary reward (Dichter, Felder, et al., 2012). Atypical reward processing in response to money is also seen in MDD, specifically in the context of anhedonia, which causes severe deficits in motivation and reward-based decision-making (Treadway et. al, 2012). Notably, the present correlations remained significant when controlling for severity of ASD symptoms, which indicates the correlation between decreased hedonic capacity and decreased motivated behaviors is contributed to by depressive symptoms present in individuals with High Functioning ASD (HFA).

Given that results suggest effort-based decision-making in individuals with ASD is related to the presence of depressive symptoms, there are important clinical implications in terms of ASD treatment. There is a ~43% comorbidity between ASD and MDD, and a significant proportion of this percentage is made of individuals with HFA (Sterling et. al., 2008). Individuals with HFA tend to present as socially awkward and thus struggle to develop social relationships both in casual and professional environments; however, given their average to above average level of intelligence, these individuals often have enough social awareness to understand they are being treated differently than those around them (Sterling et al., 2008). This may result in feelings of loneliness, which can contribute to the social isolation already present in ASD and, consequently, depressive symptoms. Therefore, our findings of impaired hedonic capacity in an ASD sample may be a reflection of depressive symptoms. Though ASD symptoms are pervasive, if the impaired hedonic capacity in ASD is more related to depressive symptoms, treatment measures for HFA should consider incorporating treatment for depressive symptoms, specifically anhedonia.

The present study was limited in that we did not exclude participants who were on medication or those who met criteria for comorbid psychiatric disorders outside of MDD. Consequently, it is also possible that the negative correlation between CDI/BDI results and sensitivity to increasing reward magnitude are the byproduct of confounding medication effects or psychiatric comorbidities. The striatum has been implicated in reward predication mechanisms, and endogenous dopamine has been shown to increase in this area when SSRIs are administered (Smith et. al., 2009 & Tanaka et. al., 2004). A number of adolescents in our study reported regularly taking an SSRI at time of assessment. Therefore, it is possible that this medication had altered neural mechanisms in the striatum such that it mediated the relationship between

depressive symptoms and reward sensitivity, making it appear typical. Regarding the possible impact of additional comorbidities, 61% ($N = 30$) of our sample met criteria for comorbid psychiatric disorders outside of MDD. More specifically, 43% percent of our sample ($N = 21$) met criteria for either an ADHD and obsessive-compulsive disorder, which have been shown to impact decision-making (Must et. al., 2005 & Paloyelis et. al, 2012). Accordingly, symptoms of these disorders may have acted as confounds in our study.

This limitation is also relevant in terms of hedonic capacity. Since hedonic capacity is related to dopamine, medication alleviating depressive symptoms could also affect the significant relationships seen between consummatory pleasure and high reward probability, as well as medium and low reward magnitude. Further, we incorporated two versions of the MINI: the MINI-KID in which parents report on symptoms versus the adult version of the MINI in which adolescents >18 reported on their own symptoms. This could have impacted our MDD diagnosis outcomes because individuals with ASD often lack insight into their own emotions, and thus may not be able to accurately report their depressive symptoms. The CDI and BDI present the same problem to our dimensional measure of depression symptom severity because they are both self-report as well. Finally, the MINI, CDI, and BDI were all limited in that our study was focused on the depressive symptom of anhedonia, but these measures contain only a few questions about this specific symptom. Future research on the topic should control for the aforementioned confounding factors, and consider utilizing a measure on depression more focused on anhedonia. Additionally, researchers could benefit from adding control groups of (1) individuals without clinically significant depression and ASD, and (2) individuals with clinically significant depression but no ASD to their studies. This would allow researchers to obtain comparable scores on the BDI, CDI, and TEPS.

Overall, the present findings add to the body of literature suggesting that comorbid psychiatric disorders should be considered when treating individuals with ASD. Specifically, they show that there is a relationship between depressive symptom severity and reward-based decision-making. Moreover, they supported our hypothesis that increased hedonic capacity correlated with increased reward sensitivity, such that the effort-based decision-making of individuals with ASD and greater hedonic capacity was more similar to TDCs than that of individuals with ASD and lower hedonic capacity. Further research on this topic could yield important information regarding depressive symptoms, and specifically anhedonia and altered hedonic capacity, as an important explanatory variable for the altered reward processing seen in ASD.

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Appendix

Table 1. *Mean (and Standard Deviation) scores on demographic and clinical measures for the ASD group.*

	ASD (n=49)
	Mean (SD)
Age	15.98 (2.59)
Full Scale IQ (FSIQ)	102.94 (16.89)
Male: Female ratio	44:5
ADOS SA	11.17 (3.52)
ADOS RRB	3.83 (1.66)
Participant Race	
African-American	4
Caucasian	44
Hispanic	1
Asian American	0
Other	0

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

Table 2. *Correlations between proportion of hard task choices on EEfRT and questionnaires in the ASD group, controlling for severity of ASD symptoms with the SRS*

Variables		Proportion Hard Task Choices						Change in Proportion Hard Task Choices					
		Reward Magnitude			Reward Probability			Change in RM			Change in RP		
		Small	Med	Large	12%	50%	88%	L-M	M-S	L-S	88-50%	50-12%	88-12%
	BDI/CDI	-0.09	-0.02	-0.08	-0.29*	0.13	0.05	-0.21	0.23	0.07	-0.08	0.40**	0.33*
	TEPS Total	0.22	0.21	0.11	0.23	0.04	0.21	0.06	-0.12	-0.07	0.15	-0.21	-0.08
	TEPS-A	0.06	0.07	0.03	0.14	-0.05	-0.001	0.07	-0.03	0.03	0.05	-0.18	-0.14
	TEPS-C	0.34*	0.31*	0.17	0.27	0.12	0.37**	0.03	-0.18	-0.15	0.22	-0.18	0.003

*p<.05, **p<.01
L = Large, M = Medium, S = Small
RM = Reward Magnitude
RP = Reward Probability
SRS = Social Responsiveness Scale

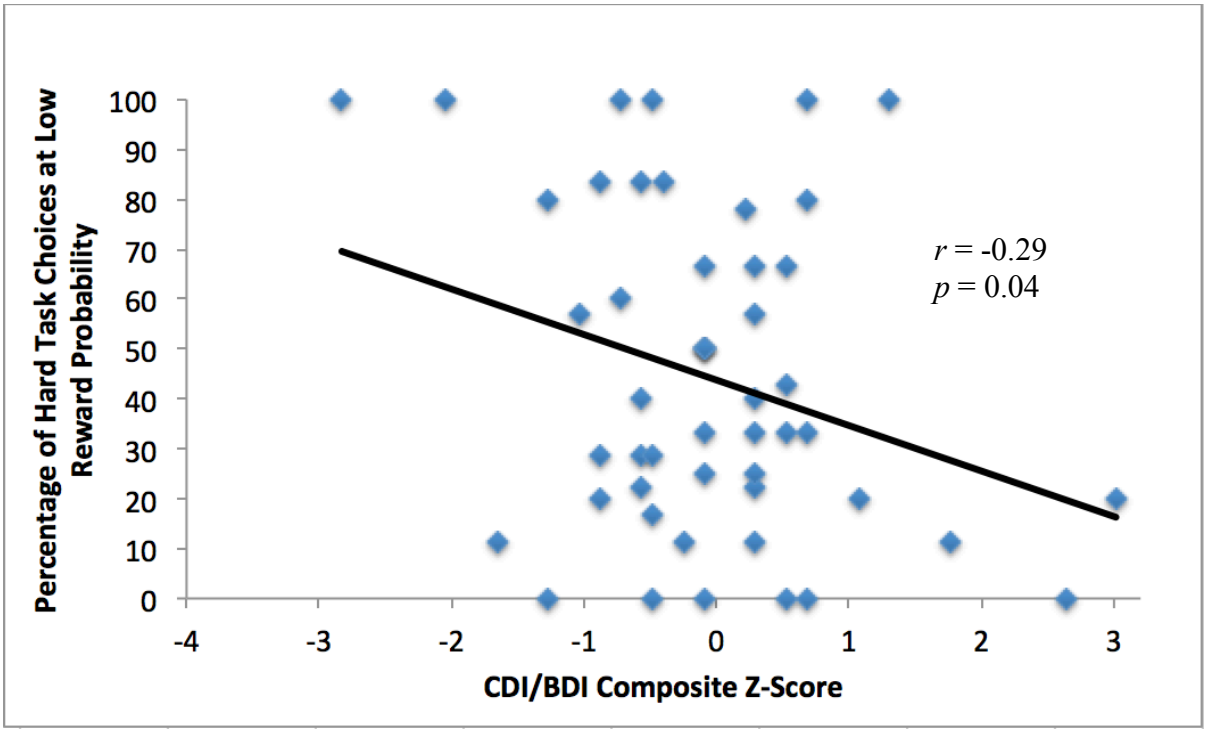

Figure 1. Correlations with CDI/BDI composite z-scores and percentage of EEfRT hard task choices at low reward probability within the ASD group

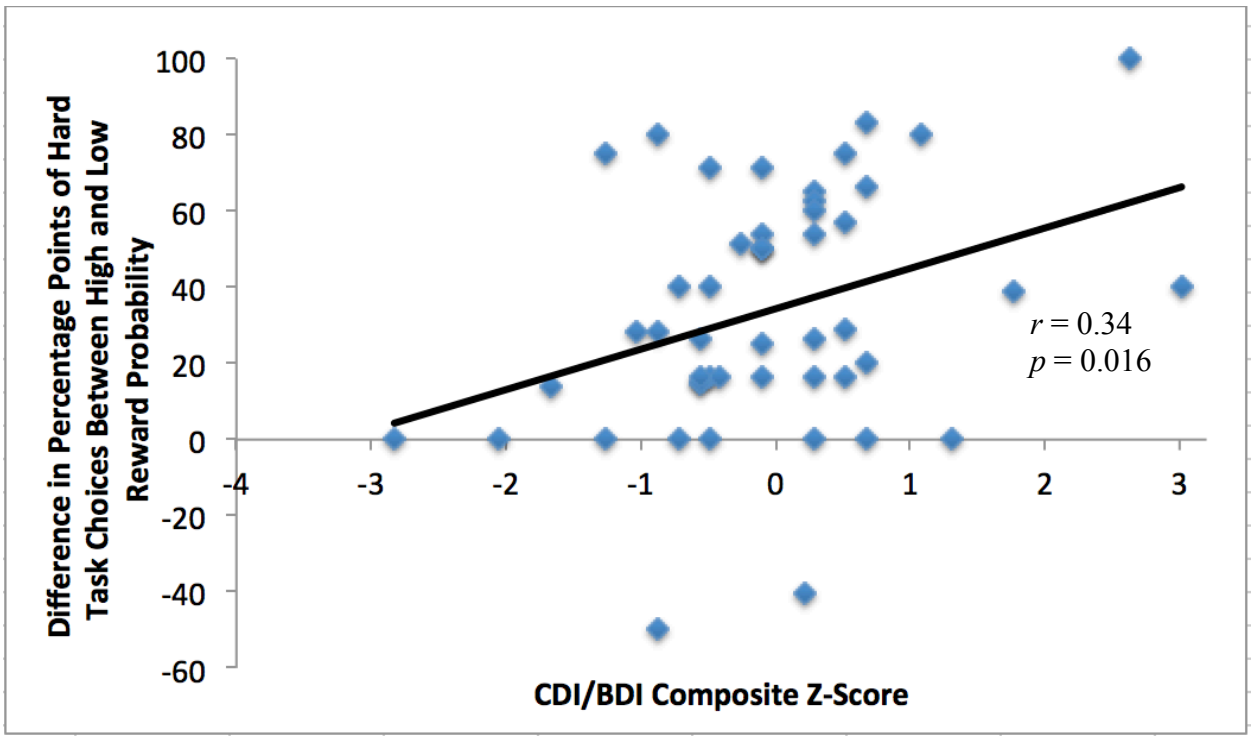

Figure 2. Correlations with CDI/BDI composite z-scores and difference in percentage of hard task choices made from high to low reward probability within the ASD group

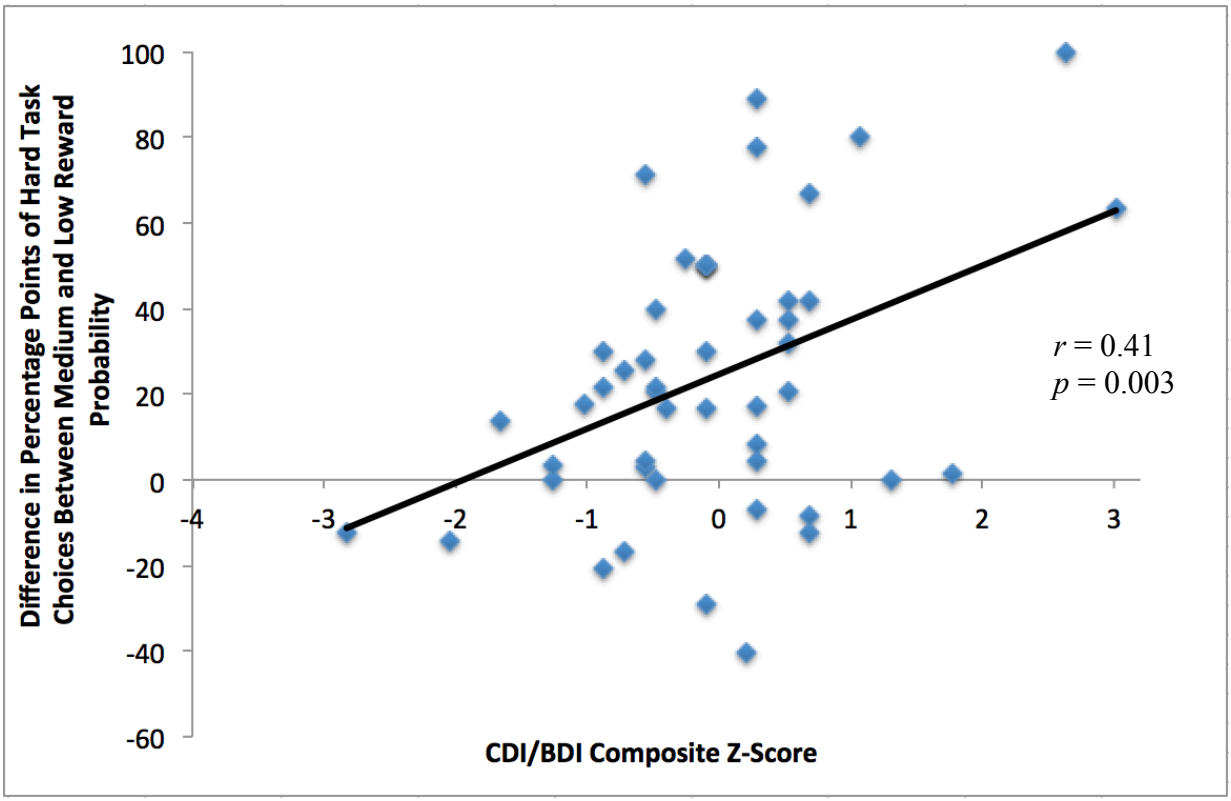

Figure 3. Correlations with CDI/BDI composite z-scores and difference in percentage of hard task choices made from medium to low reward probability within the ASD group

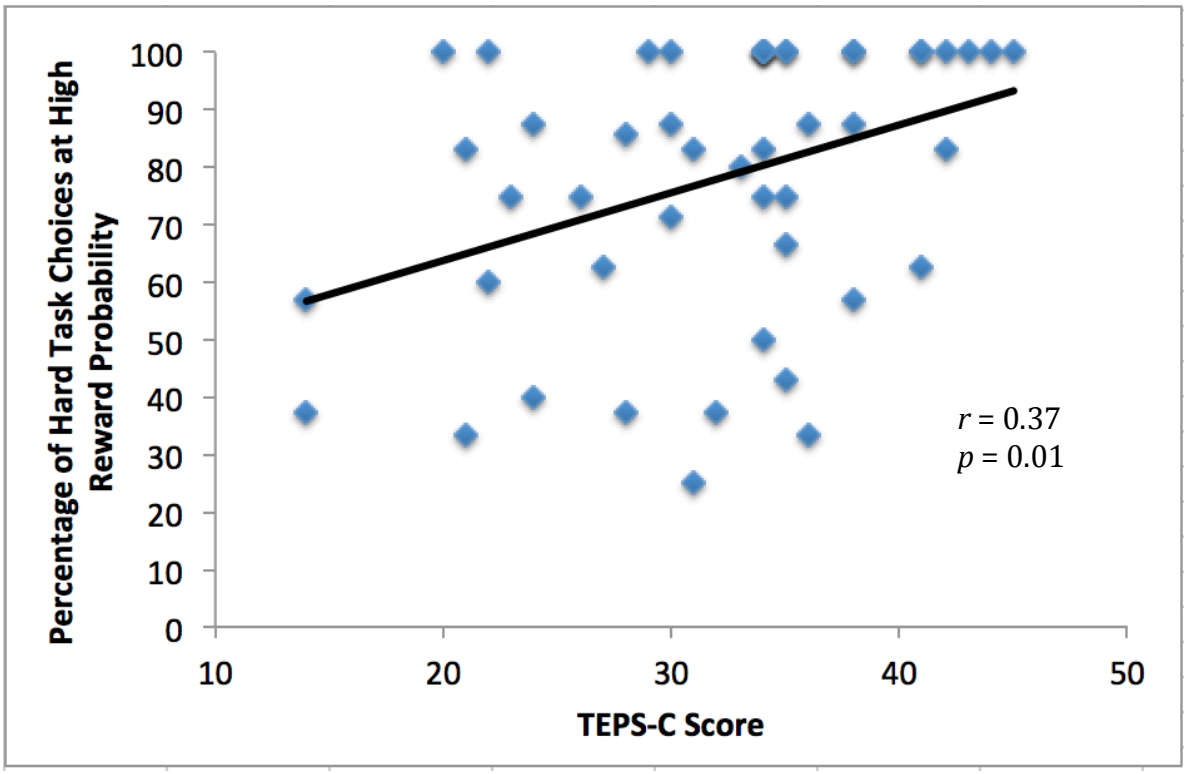

Figure 4. Correlations between TEPS-C scores and percentage of hard task choices at high reward probability within the ASD group

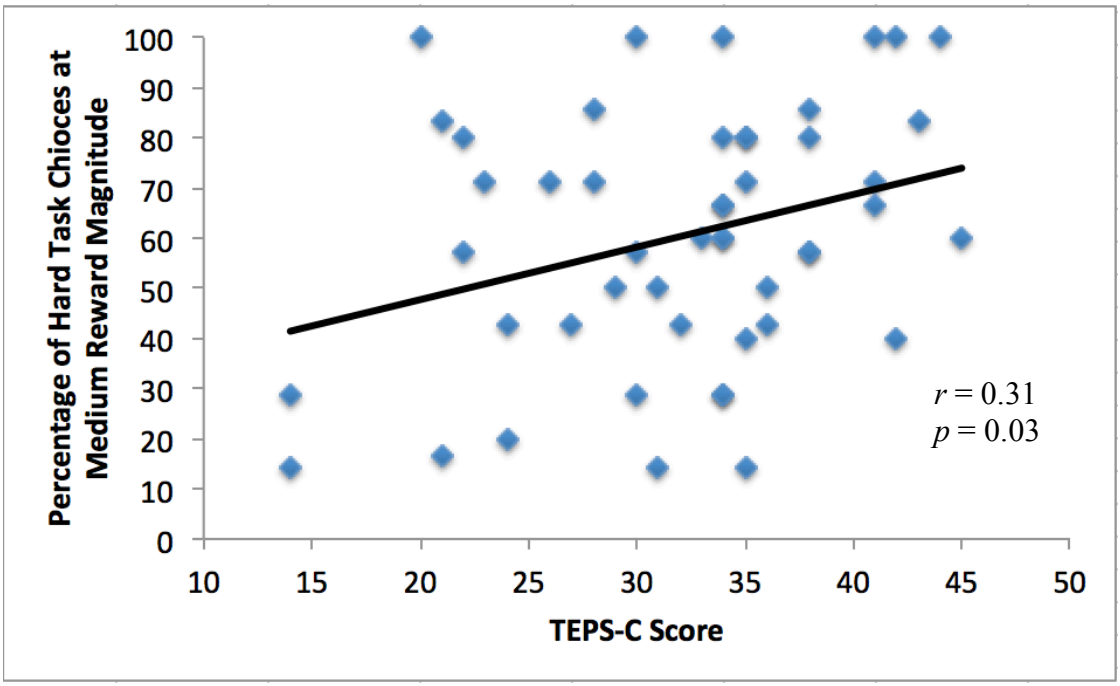

Figure 5. Correlations between TEPS-C scores and percentage of hard task choices at medium reward magnitude within the ASD group

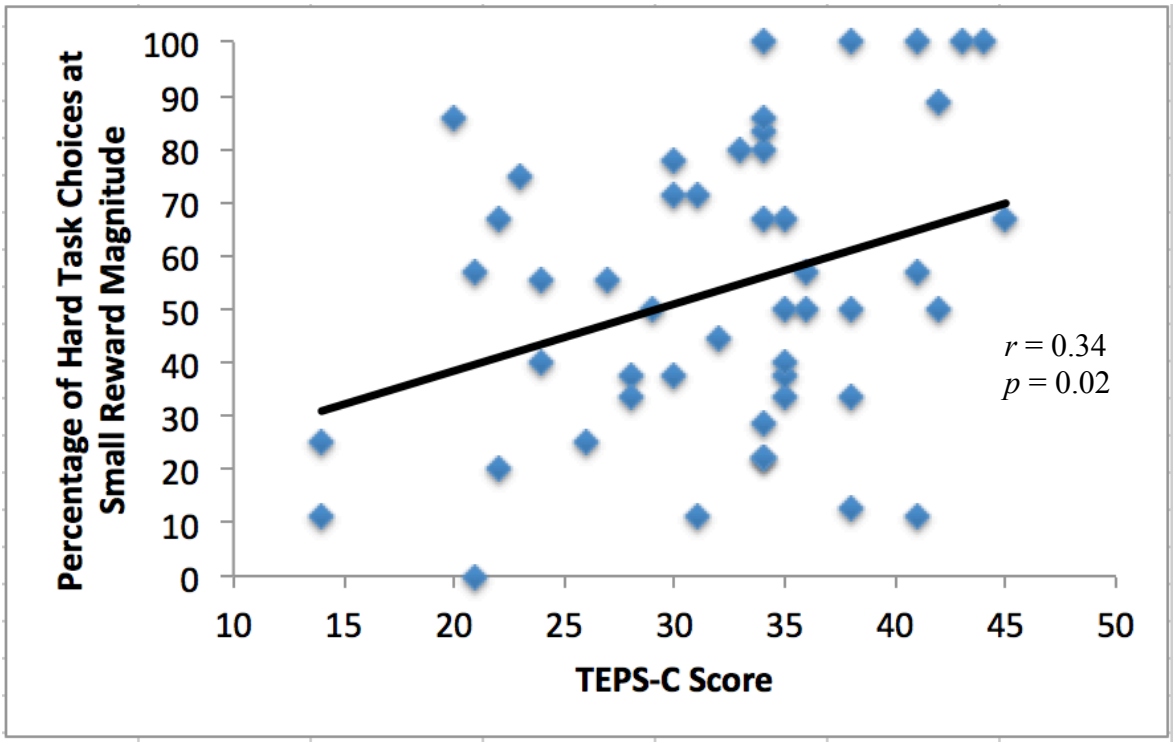

Figure 6. Correlations between TEPS-C scores and percentage of hard task choices at small reward magnitude within the ASD group