Neural Circuitry of Reward Loss in Autism Spectrum Disorders

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Abstract

The goal of this study was to examine the differences in neural activation between children with autism spectrum disorders (ASD) and typically developing (TD) children in response to the loss of potential monetary or social rewards. Reward gain paradigms have implicated the ventral striatum as hypoactive in ASD adults, though reward loss in ASD children has yet to be examined. To measure the neural responses in anticipation and outcome phases of the loss of rewards, 15 ASD children and 10 TD children performed a behavioral task during an fMRI scan in which he or she could maintain a set amount of money or see a neutral face if successful. If unsuccessful, the participant would lose a dollar or see a frowning face depending on the trial reward type. Results indicated significant hypoactivity in the dorsal striatum for the ASD group during the anticipation of viewing facial images. Results also indicated a significant interaction of thalamus activation by reward type between the TD and ASD groups. Hypoactivity of the dorsal striatum for ASD children in anticipation of avoiding social rejection suggests a deficit in learning the expected outcomes of social stimuli and response relationships. The interaction of thalamus activity between the groups may suggest ASD children experience difficulty in modulating behavior in negative social contexts, but not for monetary frameworks. Future research should focus on examining these findings with larger samples and among ASD adults.
Neural Circuitry of Reward Loss in Autism Spectrum Disorders

According to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV), individuals with Autism Spectrum Disorders (ASD) are characterized by deficits in social interaction and communication as well as restricted repetitive behaviors (American Psychiatric Association, 1994). Past findings have pointed to the possibility that core impairments of reward circuitry may be the cause of the social impairments in individuals with ASD (Dawson et al., 2004). One of the key implications of the reward circuitry system is determining the motivation of individuals to seek out different rewarding stimuli. Etiologically, the social motivation hypothesis asserts that the lack of reward processing of social stimuli by infants with ASD may result in the presentation of maladaptive social dysfunction throughout the remainder of his or her life (Schmitz et al., 2008; Scott-Van Zeeland, Dapretto, Ghahremani, Poldrack, & Bookheimer, 2010). Similarly, the feature of having restricted repetitive behaviors, which are associated with strong desires for sameness and intense interests in constricted subjects (American Psychiatric Association, 1994), may also result from irregular functioning of the reward processing systems of individuals with ASD (Dichter et al., 2012).

Researching Reward Processing

The reward processing circuitry of the brain plays a vital role in guiding motivated behavior. While motivation itself is essential for adaptive and well-adjusted living, the specific stimuli that individuals find motivating or rewarding have a profound influence on how they will act towards those things in the future. More specifically, reward processing is broken down into two phases: the anticipation of a reward and the resultant outcome of a reward. Though these
two phases together reflect reward processing, research indicates that the neural circuitry of the processes are fundamentally separate (Knutson, Fong, Adams, Varner, & Hommer, 2001).

In examining the neural correlates of reward processing, functional magnetic resonance imaging (fMRI) is a proven method for researching social rewards and ASD (Dichter et al., 2012; Dichter et al., 2012; Kohls et al., 2011; Larson et al., 2011; Schmitz et al., 2008; Scott-Van Zeeland et al., 2010). Prior research studies using fMRI have determined a reward network of the brain to be composed of the anterior cingulate (ACC), orbitofrontal cortex (OFC), and the ventral striatum (VS) (O’Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). According to Breiter and Gasic (2004), fMRI has become a gold standard for examining the underlying neural processes of motivation that give insight to the etiological basis for neuropsychiatric disorders. Since understanding motivation is important for studying behavior, comprehension of how ASD individuals differ in social motivation compared to typical individuals is necessary to improve the social functioning of autistic individuals.

**Reward Processing and Autism**

For most individuals, social situations begin to elicit a positive response in the brain at a very young age, but research indicates that this is not the case in the majority of individuals with ASD (Dawson et al., 2004). According to the “social motivation hypothesis,” a diminished neural reward response of infants with ASD to social stimuli may cause the individuals to develop as less social than TD individuals and lead to many of the core deficits of ASD (Schmitz et al., 2008; Scott-Van Zeeland et al., 2010). Because of the reduced social motivation, social stimuli are not found to be as rewarding and are subsequently less likely to be sought out.
Reward processing was studied in ASD by Scott-Van Zeeland et al. (2010) using monetary and social rewards. In their study, an implicit learning task was employed with separate trials for the different reward types across both TD and ASD subjects. Results indicated that ASD participants had decreased activity for the monetary reward task in the ventral striatum (VS), an important region for coding the incentive motivation salience of potential future rewards. Furthermore, the results also found an even greater hypoactivation of the VS for the ASD group for the social reward task when compared to TD participants, suggesting that ASD individuals have specifically low neural responses to social rewards (Scott-Van Zeeland et al., 2010).

Further research on VS activation and autism has been conducted by Dichter et al. (2012) in a study examining the neural responses to rewards also differing by type. In this study, the researchers focused on nucleus accumbens (NAc) activation; a more specified region of the VS known to be associated with motivation for achieving potential future rewards. The researchers employed a modified Monetary Incentive Delay (MID) task in which participants fast responses were rewarded with either money or a picture of an object known to be particularly salient for many ASD individuals. Neural activation was measured during both the anticipation and outcome of the reward. Results showed hypoactivation of the NAc during the outcome phase to monetary rewards of the ASD group, but no significant difference between groups based on the object images. Also, participants in the ASD category showed lower activation during the anticipatory phase regardless of reward type. These findings implied that the characteristic lack of social motivation of ASD may result from the broader reduced activation for the anticipation of any type of reward (Dichter et al., 2012).
Reward Loss and Reward Gain

While many studies have been conducted assessing the neural circuitry of various types of reward gains as it pertains to ASD (Dichter et al., 2012; Dichter et al., 2012; Kohls et al., 2011; Larson et al., 2011; Schmitz et al., 2008; Scott-Van Zeeland et al., 2010), no research has been conducted to determine whether there is a fundamental difference in reward anticipation or outcome in autism verses TD participants when rewards are lost rather than gained. Given recent findings that suggest that there may be a more general impairment of reward processing in ASD as opposed to a deficit strictly based on social stimuli (Kohls et al., 2011), it is important to gain comprehensive knowledge on all aspects of reward and motivation to further understanding of the basis of social deficits in ASD. The significance of considering reward loss in addition to reward gain has been recognized in a number of other neuropsychological disorders (Elman et al., 2009; Gotlib et al., 2010; Vollm et al., 2007), but has yet to be researched for autism.

In 2007, Vollm and colleagues noted that looking at the loss, or punishment, condition of reward processing and motivation could provide insight by determining if certain behavior is a result of positive goal-directed behavior or a diminished sensitivity to punishment. In the study, the researchers used monetary gain and monetary loss tasks to employ the two systems for comparison between healthy participants and Cluster B (antisocial and borderline) personality disorder participants. This distinction between motivations for gaining rewards versus avoidance of reward loss was shown to be important etiologically as different psychopathology may have resulted depending on which psychological process was impaired (Vollm et al., 2007).

The importance of studying reward loss along with reward gain can also be seen through recent studies of reward processing in individuals with Post-Traumatic Stress Disorder (PTSD).
In a study by Elman et al. (2009), fMRI was used to study the anticipation and outcome of both monetary reward gain and loss to compare a PTSD group with a healthy group. The study results showed that a lower activation of the VS for monetary gains compared to losses was associated with reduced social motivation. The implementation of using a behavioral test for reward loss was important in providing a framework for comparison of the participants’ relative motivation for achieving a reward against their motivation to avoid losing a similar reward. These findings carried important treatment relevance, as they implied that behavioral therapy or psychopharmacological treatments should be directed towards increasing reward processing activation (Elman et al., 2009).

Furthermore, the clinical significance of researching reward loss for psychopathological disorders was also seen through the findings of Gotlib et al. (2010) on individuals at a high familial risk for Major Depression. During their study, the experimenters used a modified MID task where 10-14 year old girls were able to gain or lose points that could be later redeemed for predetermined prizes. The results indicated that there was a fundamental difference between the reward gain and loss paradigms, as high-risk girls showed lower VS activation during reward anticipation and outcome but employed an additional brain region, the dorsal anterior cingulate cortex (dACC), during reward loss compared to essentially no activation in the dACC for low-risk girls (Gotlib et al., 2010). Activation of the dACC indicated that the high-risk girls may be more likely to engage in risk-taking behavior (Gotlib et al., 2010), a finding which would not have been posited without the inclusion of reward loss as a task in the study.
The Current Study

While the anticipation and outcome of both social rewards and monetary rewards have been studied as they relate to ASD (Dichter, Richey, Rittenberg, Sabatino, & Bodfish, 2012; Kohls et al., 2011; Larson, South, Krauskopf, Clawson, & Crowley, 2011; Schmitz et al., 2008; Scott-Van Zeeland et al., 2010), there have been essentially no studies conducted to assess the correlates of the loss of such rewards. The present study examines the neural processing of reward loss in both the anticipation and outcome of children with ASD compared to typically developing (TD) children. This paradigm will be administered through a modified Monetary Incentive Delay (MID) task (Knutson, Westdorp, Kaiser, & Hommer, 2000) with conditions varied according to stimulus type (social or non-social) and reward type (gain or loss). Furthermore, the reward processing system of individuals with ASD has been found to be impaired through several past research studies (Dichter et al., 2012; Dichter et al., 2012; Kohls et al., 2011; Larson et al., 2011; Schmitz et al., 2008; Scott-Van Zeeland et al., 2010). These studies have often utilized a modified MID task (Knutson, et al., 2000) designed to create a paradigm for examining the neural correlates of reward processing based on the anticipation and outcome phases of different types of rewards (Delmonte et al., 2012; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Dichter et al., 2012). This study will be the first to employ a modified MID task based on reward loss in studying ASD.

Based on past research discussed thus far, I hypothesize that individuals with ASD will display reduced VS activity in all trials of reward loss. Additionally, I also hypothesize the ASD group to display further diminished VS activity for socially based reward trials compared to a typically developing control group based on research suggesting a more general deficit of motivation for ASD individuals (Kohls et al., 2011).
Methods

Participants

Recruitment of this study aimed for 20 TD children and 20 children with diagnoses of high-functioning autism. Unfortunately, data for only 15 autistic children and 10 typically developing children was collected prior to analysis. The age of the participants ranged from 9 to 18 years old with the autistic group being collectively older ($M=15.06$ years old, $SD=2.97$ years old) than the control group ($M=13.28$ years old, $SD=3.36$ years old). The recruitment of children with ASD was conducted through the Autism Subject Registry and TD children were recruited through the Child Development Research Registry. Each of these registries is maintained by the Carolina Institute for Developmental Disorders. All children included in the ASD group were previously diagnosed with an autism spectrum disorder prior to the study. Each ASD participant scored according to their diagnosis as well on the Autism Diagnostic Observation Schedule (ADOS) – Module 3 or 4.

Clinical Measures

Each participant was scored on multiple neuropsychological tests prior to taking part in the study task. The Social Responsiveness Scale (SRS) (Constantino et al., 2003) was used to measured social impairment symptoms of autism. In order to assess restricted repetitive behavior symptomatology, the Repetitive Behavior Scale – revised (RBS-R) (Bodfish, 1999) and the Inventory for Repetitive Behaviors (IRB) (Bodfish, 2003) were also administered.
FMRI Mock Scan

In order to acclimate participants to testing conditions prior to scanning sessions, all children completed a brief training of the behavioral task of the study while being in a mock fMRI scanner. All participants scored >95% on a training behavioral task simulating the MID task during the mock scan.

Reward Stimuli

The modified incentive delay (MID) task was employed during separate runs for four different reward conditions: monetary gain, monetary loss, social gain, and social loss. For these runs, participants had the chance to gain money, avoid losing money, gain images of faces with happy expressions, or avoid seeing faces with sad expressions based on their response times.

FMRI Imaging Session

Each of the four MID task runs were conducted while in the fMRI scanner with 40, 6 second trials. At the start of each trial, one of two cue shapes (a grey triangle for potential success trials and a blue circle for non-potential success trials) were presented for 250 milliseconds to indicate to the participant the implications of each trial. After the shape presentation, a crosshair was displayed on the screen to fixate the participants as a delay for 2000 – 2500 milliseconds before the appearance of a target to cue participants to push a button as quickly as possible. After the target response, performance feedback informed the participants if they successfully responded quickly enough to “win” and indicated if they received the run-dependent reward. The task was programmed for participants to be successful on 67% of the task trials.
The four MID task runs were characterized by reward type as either monetary or social and by the gain or loss paradigm and thus were described as “Money Gain,” “Money Loss,” “Face Gain,” and “Face Loss.” For the social tasks, participants had the chance to either “gain” the image of a smiling face or avoid the “loss” of viewing a face with a sad expression. Non-social tasks involved monetary rewards in which participants were given the chance of gaining a dollar or avoid losing a dollar from a set amount of money prior to the task. At the beginning of each trial, participants were shown either a grey triangle or a blue circle. If shown the grey triangle, participants were aware that their performance on the task would determine if they received, or avoided losing, a reward. If shown the blue circle, participants were aware that they did not have the opportunity to gain an award or avoid losing a reward regardless of their performance on the task. For potential success gain runs (Money Gain or Face Gain), successful completions of the response task resulted in participants winning a dollar or seeing a happy face. For potential success loss runs (Money Loss or Face Loss), participants avoided losing a dollar from a prior given amount or avoided seeing a frowning face. Regardless of the amount of money won or lost through the trials, participants were given the maximum amount at the completion of the session. Summation of these tasks is provided through Figure 1 below.
Figure 1. Visual Representation of the Modified MID Tasks for Social and Nonsocial Runs
Imaging Methods

The methods for collecting the imaging data for the study are similar to those employed by Dichter et al. (2012). The scanning of each participant was conducted using a “GE Health Technologies, 3 Tesla Signa Excite HD scanner with 50-mT/m gradients (General Electric, Waukesha, Wisconsin, USA). Head movement was restricted using foam cushions. An eight-channel head coil was used for parallel imaging. Thirty high resolution images were acquired using a 3D fast SPGR pulse sequence (TR = 7.332 ms; TE = 3.032 ms; FOV = 22 cm; image matrix = 256^2; voxel size = 0.86 × 0.86 × 3.80 mm) and used for coregistration with the functional data. Structural images were aligned in the near-axial plane defined by the anterior and posterior commissures. Whole-brain functional images consisted of 30 slices parallel to the AC-PC plane using a BOLD-sensitive gradient-echo EPI sequence with higher-order shimming, at TR of 2,000 ms (TE: 30 ms; FOV: 22 cm; isotropic voxel size: 3.4375 × 3.4375 × 4.0000). Runs began with 4 discarded RF excitations to allow for steady state equilibrium (Dichter et al., 2012).”

Symptom Correlations

Following determination of subcortical brain regions with significant differences between the groups, correlations were run to examine if normalized activation patterns in the identified regions were correlated with improved symptom test scores. These correlations were run using Microsoft Excel with participants within the ASD group using scores from the ADOS, SRS, RBS-R, and IRB neuropsychological tests.
Results

Although there was no support for the hypotheses of hypoactivation of the VS for the ASD group compared to the control group, there were several interesting findings.

Imaging Results

Because of time limitations for the analysis of data for this thesis, the Money Loss and Face Loss conditions were selected to be analyzed over the Money Gain and Face Gain conditions, which have been examined in prior literature. Differences in brain activation were evaluated by observing significantly different clusters of activity between the ASD and control groups during the anticipation and outcome phases of the Money Loss and Face Loss trials. Despite the small sample size of the study, a conservative threshold for significant activation (Z>2.54) was used during analysis.

Analysis of the Face Loss condition revealed a main effect of group differences during the anticipation phase of the task. For this condition, the ASD group showed a significant hypoactivation of the left putamen, right caudate, left caudate, and the right thalamus. The activation data and locations of the respective clusters are summarized below in Table 1 and visual representations of the differences of the caudate and putamen are shown in Figure 2.
### Table 1.

*Significant Main Effect Differences in Activation of Control > ASD during the Anticipation Phase of Face Loss Trials*

<table>
<thead>
<tr>
<th>Region</th>
<th>Cluster Size (mm$^3$)</th>
<th>Mean Activation (Z)</th>
<th>Max Activation (Z)</th>
<th>MNI Brain Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Putamen</td>
<td>88</td>
<td>2.82</td>
<td>3.34</td>
<td>-20  12  -10</td>
</tr>
<tr>
<td>Right Caudate</td>
<td>48</td>
<td>2.81</td>
<td>3.39</td>
<td>10   6   10</td>
</tr>
<tr>
<td>Left Caudate</td>
<td>220</td>
<td>2.88</td>
<td>3.53</td>
<td>-10  6   10</td>
</tr>
<tr>
<td>Right Thalamus</td>
<td>230</td>
<td>2.78</td>
<td>3.33</td>
<td>16  -10  14</td>
</tr>
</tbody>
</table>
**Figure 2.** Visual representations of brain regions significantly less activated by the ASD group relative to the control group during Face Loss anticipation.
The other main effect of differences between the two groups occurred during the outcome phase of the Money Loss trial. The ASD group showed a significant hypoactivation of the left thalamus, right thalamus, and the right pallidum compared to the control group. The activation data and locations of the respective clusters are summarized below in Table 2 and a visual representation of the differences of the thalamus is shown in Figure 3.
Table 1.

*Significant Main Effect Differences in Activation of Control > ASD during the Outcome Phase of Money Loss Trials*

<table>
<thead>
<tr>
<th>Region</th>
<th>Cluster Size (mm^3)</th>
<th>Mean Activation (Z)</th>
<th>Max Activation (Z)</th>
<th>MNI Brain Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Thalamus</td>
<td>21</td>
<td>2.71</td>
<td>3.09</td>
<td>14 -20 -4</td>
</tr>
<tr>
<td>Left Thalamus</td>
<td>47</td>
<td>2.95</td>
<td>3.60</td>
<td>-12 -4 4</td>
</tr>
<tr>
<td>Right Pallidum</td>
<td>494</td>
<td>2.87</td>
<td>3.67</td>
<td>14 0 -2</td>
</tr>
</tbody>
</table>
Figure 3. Visual representations of brain region significantly less activated by the ASD group relative to the control group during Money Loss outcome.
In addition to the two main effects discussed in the study, a Group (ASD, Control) by Reward Type (Face, Money) interaction was also found between the anticipation phases of the Money Loss and Face Loss conditions. This interaction revealed the left thalamus as being significantly more activated by the ASD group in response to the anticipation phase of the Money Loss trials, but the ASD group showed significantly lower activation of the left thalamus than the control group during the anticipation phase of the Face Loss condition. The activation data and location of the significant cluster is summarized below in Table 3 and a graphical representation of the differences of the thalamus activation is shown in Figure 4.
Table 3.

*Significant Interaction Effect of Activation between Groups of the Anticipation Phases of Money Loss and Face Loss Trials*

<table>
<thead>
<tr>
<th>Region</th>
<th>Cluster Size (mm^3)</th>
<th>Mean Activation (Z)</th>
<th>Max Activation (Z)</th>
<th>MNI Brain Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Thalamus</td>
<td>99</td>
<td>2.95</td>
<td>3.91</td>
<td>-8 -30 12</td>
</tr>
</tbody>
</table>
Figure 4. Graphical representation of the significant interaction effect of activation between groups of the anticipation phases of Money Loss and Face Loss trials.
Correlational Results

Follow up correlational analysis of the significantly different brain regions between groups displayed a number of interesting trends for symptomatology data. Two of the strongest correlations implicated caudate activity during the anticipation phase of the Face Loss trials as being correlated to both stereotyped behavior and insistence on sameness scores within the ASD group. For the IRB – Stereotypies subscale scores, both the right caudate ($r = -.46$, $p = .08$) and the left caudate ($r = -.33$, $p = .23$) showed trends of lower scores for individuals with greater caudate activation during the Face Loss anticipation phase. Similarly, lower scores on the IRB – Insistence on Sameness subscale were correlated with greater levels of activation within the ASD group also for the right caudate ($r = -.41$, $p = .12$) and the left caudate ($r = -.37$, $p = .18$). Lastly, the strongest correlation occurred between scores of the ASD group on the RBS-R Restricted Behavior subscale and thalamus signal activation during the outcome phase of the Money Loss condition. For this association, higher scores on the RBS-R – Restricted Behavior subscale were correlated with greater activation signal intensities for both the right thalamus ($r = .71$, $p = .003$) and the left thalamus ($r = .47$, $p = .08$). Visual representations of these correlational data are provided below in Figures 5, 6, and 7.
Figure 5. Graphical representation of the negative correlation between caudate signal intensity and IRB – Stereotypies scores within the ASD group.
Figure 6. Graphical representation of the negative correlation between caudate signal intensity and IRB – Insistence on Sameness scores within the ASD group.
Figure 7. Graphical representation of the positive correlation between thalamus signal intensity and RBSR – Restricted Behavior scores within the ASD group.
Behavioral Results

Reaction time measurements indicated that the ASD group not only was significantly quicker for most trials (non-potential reward tasks and potential reward tasks), but also on all trials combined. Student’s t-tests were performed to examine the differences within each condition between groups and found the ASD group to perform significantly quicker during trials for Money Gain (Reward), Money Gain (Non-reward), Face Gain (Reward), Face Gain (non-reward), Face Loss (Reward), Face Loss (Non-reward), and as a group in all total trials. The means and t statistics are summarized below in Table 4 and are displayed graphically in Figure 8.
Table 4.

*Reaction Time Means for Groups during Performance for Each Task Type*

<table>
<thead>
<tr>
<th>Group</th>
<th>Control (ms)</th>
<th>ASD (ms)</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Money Gain Reward</td>
<td>229.88</td>
<td>206.50</td>
<td>-2.71**</td>
<td>280</td>
</tr>
<tr>
<td>Money Gain Non-reward</td>
<td>240.95</td>
<td>218.40</td>
<td>-2.07*</td>
<td>237</td>
</tr>
<tr>
<td>Money Loss Reward</td>
<td>246.87</td>
<td>236.33</td>
<td>-1.48</td>
<td>251</td>
</tr>
<tr>
<td>Money Loss Non-reward</td>
<td>254.17</td>
<td>259.61</td>
<td>0.59</td>
<td>214</td>
</tr>
<tr>
<td>Face Gain Reward</td>
<td>243.15</td>
<td>215.98</td>
<td>-3.10**</td>
<td>306</td>
</tr>
<tr>
<td>Face Gain Non-reward</td>
<td>260.70</td>
<td>235.06</td>
<td>-2.52*</td>
<td>230</td>
</tr>
<tr>
<td>Face Loss Reward</td>
<td>241.54</td>
<td>211.50</td>
<td>-3.03**</td>
<td>239</td>
</tr>
<tr>
<td>Face Loss Non-reward</td>
<td>257.15</td>
<td>227.22</td>
<td>-2.75**</td>
<td>247</td>
</tr>
<tr>
<td>Total</td>
<td>242.76</td>
<td>224.65</td>
<td>-5.19***</td>
<td>1813</td>
</tr>
</tbody>
</table>

*Note.* *p* < .05, **p** < .01, ***p*** < .001
Figure 8. Graphical representation of mean response times for each group during performance of each task type with indicated significant differences between groups.
Discussion

Instrumental Social Learning

Though prior research has found hypoactivation in the ventral striatum to be common for autistic individuals for paradigms of reward gain (Dichter et al., 2012; Dichter et al., 2012; Scott-Van Zeeland et al., 2010), the results of this study suggest abnormal functioning of the subcortical regions of the dorsal striatum may impact autistic reward loss processing for social situations. As discussed, the caudate and the putamen, both regions of the dorsal striatum, were significantly hypoactive in the ASD group compared to the control group of the study during the anticipation phase of the Face Loss condition. In order to psychologically interpret these findings, it is important to consider the past research on the complementary roles of the ventral and dorsal striatum.

According to the studies of O’Doherty and colleagues (2004), the ventral striatum works in the process of anticipating upcoming rewards, while the dorsal striatum stores the information of each anticipated reward from the ventral striatum. This relationship is hypothesized as an ‘actor-critic’ model in which the ventral striatum processes the action of the reward and the dorsal striatum maintains a record of the action through instrumental learning, which is used in future decision-making for similar situations (O’Doherty, 2004). In considering this relationship, the hypoactivation of the dorsal striatum during anticipation of negative social stimuli for the ASD children in this study may suggest that children with ASD have impairment in learning to anticipate negative social situations. For example, as children with typical dorsal striatum functioning may learn what actions lead to negative social situations, such as upsetting other children, children with ASD may not be able to store the necessary information from these
situations to prevent similar outcomes in future scenarios. Because of the inability to anticipate these negative social outcomes, children with ASD may continue to act in ways that are considered awkward or inappropriate by their peers. These assertions are also supported by the behavioral findings of Lin, Rangel, and Adolphs (2012) which involved adults with autism showing impairment in reward learning to be greater for social rewards than for monetary rewards.

**Autism and the Thalamus**

The results of this study revealed a group by reward type interaction effect of thalamus activation, with the ASD group displaying elevated thalamus signal activity compared to the control group during the Money Loss condition but lowered activity during the Face Loss condition. While few studies have been conducted to study thalamus activity as it relates to autism, one previous study purported a link between the thalamus and the serotonergic system to sensory impairment in ASD (Hardan et al., 2008). The thalamus is known to be a relay system for emotional processes (Nanda, Zhu, & Jansen, 2012), but Haber and Calzavara (2009) have also suggested the thalamus to be a key region for behavior modification. Given the context of instrumental social learning deficits already discussed, the diminished thalamus activation of the ASD group to social rewards could further suggest an inability of children with autism to adjust their behavior in social contexts based on their past experience. Since this reduction is not present in the monetary reward loss condition (rather the thalamus is more activated in the ASD group), these results may suggest that this lack of behavioral adjustment is restricted to negative social situations.
Autism Symptomatology and the Dorsal Striatum

The correlational results of the study indicated that as caudate activity within the ASD group increased during the Face Loss anticipation phase, scores on measures of stereotyped behavior and insistence on sameness tended to improve. While not all of these measurements yielded significant correlations, a larger sample of ASD children may have resulted in significant results given the moderate to strong correlation coefficients. Although the symptoms of stereotyped behavior, or persistent actions that are typically not adaptive, and insistence on sameness do not always present identically between the two disorders, these are each common features of both autism and obsessive-compulsive disorder (OCD). Little research has been done examining the caudate and autism symptomatology, but prior findings have implicated the dorsal striatum as being functionally reduced in patients of OCD (Harrison et al., 2009). The findings of the current study further support the notion that hypoactivity of the caudate is associated with both stereotypy behavior and insistence on sameness and may provide some context to the link between the high rate of comorbidity between autism and OCD.

The Money Loss Condition

Results from different measurements during the Money Loss condition provided some unexpected findings for the ASD group. As discussed, thalamus activity was higher for the ASD group during the anticipation phase of Money Loss than for the control group, despite being lower during Face Loss. Also, correlational data within the ASD group indicated that during the outcome phase of Money Loss, participants with higher thalamic activity tended to experience greater symptoms of restricted behavior. Lastly, the potential success and non-potential success trials of Money Loss were the only behavioral paradigms in which the ASD group did not react
to the MID task significantly quicker than the control group. While it may be difficult to psychologically interpret these results, these findings may suggest some generalized abnormal functioning of the thalamus during either anticipation or outcome phases of reward loss avoidance in autism. Further research should be directed toward these paradigms for interpretation clarity.

Limitations

The small sample size of this study (ASD n = 15; Control n = 10) is a concern for the potential variability that may influence these findings. Although finding significant differences in brain regions was encouraging given the low number of participants, the correlational results should be interpreted with caution given their lack of directionality and further reduced sample size (ASD group only). Another limitation of this study is the inability to assume that images of faces during the social conditions perfectly simulate brain responses to actual social environments. Though this paradigm has been used extensively in other research studies, it is important to consider this when generalizing the results to real-world scenarios. One final consideration is the discrepancy in age between the ASD group and the control group. The ASD group (M=15.06 years old, SD=2.97 years old) was older than the control group (M=13.28 years old, SD=3.36 years old), which could have influenced the results given the developmental changes of the brain that occur during this age range.

Implications and Future Directions

Altogether, the results of this study suggest a specific impairment of children with autism in learning to avoid inappropriate social outcomes. Furthermore, the dorsal striatum and the thalamus appear to be hypoactive in children with autism for social reward anticipation, thus
affecting their ability to learn the results of actions in a social context and to actively modify their behavior in response to social cues. Reduced caudate functioning has also been implicated as being correlated with higher rates of autism symptoms that are commonly shared with OCD. Another important finding of this study is that children with autism may not experience psychopathology of the same brain regions in response to forms of losing rewards compared to gaining rewards, as the dorsal striatum (not the ventral striatum as in reward gain) was found to be significantly aberrant in loss conditions.

The findings of this study offer a number of directions for future autism research. Primarily, future studies should address the sample limitations discussed by incorporating more participants in both the ASD and control groups and by controlling for age. Future studies should also examine reward loss in autistic adults, specifically concerning the functioning of the dorsal striatum and the thalamus during social contexts. The caudate should also be explored experimentally for links in functional activity between autism and OCD individuals as well as individuals diagnosed with both disorders to determine if the relationship with symptomatology is associative or causal in nature.
References


