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Journal

Journal of Autism and Developmental Disorders, 48(3)

ISSN

0162-3257

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Publication Date

2018-03-01

DOI

10.1007/s10803-017-3338-3

Peer reviewed

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Author manuscript

J Autism Dev Disord. Author manuscript; available in PMC 2019 March 01.

Published in final edited form as:

J Autism Dev Disord. 2018 March ; 48(3): 809–823. doi:10.1007/s10803-017-3338-3.

What are you doing with that object? Comparing the neural responses of action understanding in adolescents with and without autism

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Abstract

Understanding another’s actions, including what they are doing and why they are doing it, can be difficult for individuals with autism spectrum disorder (ASD). This understanding is supported by the action observation (AON) and mentalizing (MZN) networks, as well as the superior temporal sulcus. We examined these areas in children with ASD and typically developing controls by having participants view eating and placing actions performed in conventional and unconventional ways while functional magnetic resonance images were collected. We found an effect of action-type, but not conventionality, in both groups, and a between groups difference only when viewing conventional eating actions. Findings suggest there are not global AON/MZN deficits in ASD, and observing unconventional actions may not spontaneously activate the MZN.

Keywords

fMRI; action understanding; autism; mentalizing; intention

The ability to understand the actions and intentions of others is essential for navigating the social world. Being able to interpret and predict others’ actions allows one to adapt his or her own behavior accordingly, facilitating social interactions. One of the core diagnostic criteria for individuals with autism spectrum disorder (ASD) is a marked impairment in reciprocal social interactions (American Psychiatric Association, 2013), which may be due

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Disclosure of potential conflicts of interest
The authors declare that they have no conflict of interest.

Research involving human participants and/or animals
All procedures performed in studies involving human participants were in accordance with the ethical standards of the University of California Davis Institutional Review Board and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent
Informed consent was obtained from all individual participants and their parents/guardians included in the study.

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to deficits understanding the actions and intentions of others. When observing the actions of others, one may attend to the specific action and what is happening (such as reaching for a glass), or one may speculate about why the person is performing the action (e.g., that the person's intention is to take a drink of water.) In this way, the same action can be identified at multiple levels, from a low level describing the specific motor details of the action to a higher level where the intention of the action is inferred by the observer attributing mental states to the actor performing the action (Vallacher & Wegner, 1987). In the present study, we are interested in how individuals with ASD view goal-directed actions involving a physical object. A task was designed to prompt the viewer to consider why the person they were observing might be performing particular actions and to determine whether this differed based on the type of action being performed.

Investigations into the neural correlates of action understanding have typically focused on two neural systems: the action observation network (AON), which includes areas of the mirror neuron system (Caspers, Zilles, Laird, & Eickhoff, 2010; Molenberghs, Cunnington, & Mattingley, 2012), and the mentalizing network (MZN). Areas of the AON include the lateral dorsal and ventral premotor cortex (PMC) and inferior frontal gyrus (IFG), the inferior (IPL) and superior parietal lobules (SPL), intraparietal cortex, and along the postcentral gyrus and the superior and middle temporal gyri. These areas are ones that are typically recruited when one observes another performing an action (Caspers et al., 2010), as well as when one imagines and executes those same actions (Filimon, Rieth, Sereno, & Cottrell, 2015), and may contribute to understanding the actions of others by mapping those actions onto one's own motor system, essentially simulating a similar motor representation and thus predicting the possible outcomes of the action based on their own familiarity of the action (Keysers & Gazzola, 2006). Support for this comes from studies demonstrating higher levels of activation in the AON, as measured by functional magnetic resonance imaging (fMRI), when individuals observe actions that they are an expert in performing (Calvo-Merino, 2004; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006).

The MZN consists of the medial prefrontal cortex (mPFC), posterior superior temporal sulcus (pSTS)/temporoparietal junction (TPJ) and precuneus (Frith & Frith, 2006). The MZN has traditionally been studied within the context of attributing mental states to others, which is often referred to as Theory of Mind (ToM; Premack & Woodruff, 1978), typically by presenting verbal stories or cartoons and asking the participant to consider the beliefs or desires of the characters in the stories (Frith & Frith, 2006; Gallagher & Frith, 2003; Saxe, Whitfield-Gabrieli, Scholz, & Pelphrey, 2009).

These two networks may be involved at different levels within the action hierarchy, with the AON encoding what action is being performed, how it is being performed, and what the immediate predicted outcome of the action is, while the MZN encodes why an action may be performed from the perspective of the performer (Catmur, 2015; Spunt, Satpute, & Lieberman, 2011; Van Overwalle & Baetens, 2009). The difference in task paradigms (observing actions versus verbal stories), however, likely contributed to these networks being viewed, and studied, as separate, rather than complementary processes underlying one's ability to understand the actions and intentions of others (Keysers & Gazzola, 2007). Studies utilizing actions that may be considered out of the ordinary or unusual allow researchers to

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investigate multiple levels of action understanding, from what is occurring to how and why it is occurring, within the same task paradigm (Thioux, Gazzola, & Keysers, 2008). When one observes actions such as these, the individual recruits brain regions involved in attributing mental states to others to consider *why* the person is doing the action (for a review: Van Overwalle & Baetens, 2009). For instance, a study in which participants observed videos of people performing unusual goal-directed actions, such as bringing a coffee cup to the ear, found greater activation in the IFG (de Lange, Spronk, Willems, Toni, & Bekkering, 2008). However, this occurred when participants were judging how the action was being performed, i.e. the means of the action. When the same participants were to attend to the intention of the actor and explicitly judge whether the action was normal or unusual, there was no differentiation in areas of the AON. Instead, there was greater activation in areas of the MZN. Thus, when one explicitly considers the intention behind an action, which is to say, when they consider the intention of the *person* performing the action, it is areas within the MZN that are modulated.

Actions that are irrational have also been used to examine the interplay between these two networks, as irrational actions fall between a basic level understanding of the action being observed and asking why the action was being performed via attributing intentions to the performer (Gergely & Csibra, 2003). For example, an object is lying on a table and a hand reaches to pick up the object. If the hand moves toward the object in a direct path to pick it up, this is a rational action. If a solid barrier were placed between the hand and the object, the hand should travel in a non-direct path, reaching over or around the barrier to grasp the object. This too is rational because the hand cannot travel through the barrier and thus must change trajectory to move around the barrier to reach the object. This same action would be deemed irrational, however, if the barrier were not present, and an observer might be puzzled as to why the hand reached in the manner it did as there would be no observable reason for it to do so. One would predict that rational actions would preferentially engage the AON while irrational actions might engage the MZN. Studies utilizing such tasks, or similar, have had mixed findings when examining irrational compared to rational actions, with some finding expected increases in areas of the MZN (Brass, Schmitt, Spengler, & Gergely, 2007; Pelphrey, Morris, & McCarthy, 2004; Vander Wyk, Hudac, Carter, Sobel, & Pelphrey, 2009), while others find increases in the AON (Marsh & Hamilton, 2011), or in areas of both the MZN and the AON (Marsh, Mullett, Ropar, & Hamilton, 2014). The latter findings suggest that these networks likely work in conjunction with one another to understand the actions of others.

Few studies have examined the AON in individuals with ASD during the observation of goal-directed actions, as what is often presented are intransitive actions (Dinstein et al., 2010; Martineau, Andersson, Barthélémy, Cottier, & Destrieux, 2010) or facial expressions (Bastiaansen et al., 2011; Dapretto et al., 2006). Some have suggested that the social impairments observed in individuals with autism stem from underlying deficits in the mirror neuron system (‘broken mirror’ theory; Oberman & Ramachandran, 2007; Williams, Whiten, Suddendorf, & Perrett, 2001), which has similar overlap to the AON, proposing that one understands the actions of others by mapping those actions on to oneself. Deficits in this mapping thereby result in an inability to properly interpret the actions of others and respond appropriately. That said, there is considerable evidence countering this proposal (Hamilton,

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2013; Hamilton, Brindley, & Frith, 2007; Southgate & Hamilton, 2008). In studies that have examined specifically goal-directed actions, which is relevant to the current study, it appears that activation of the AON does not significantly differ between ASD and TD individuals (Marsh & Hamilton, 2011; XXXXXXXXX).

Similar to the ‘broken mirror’ theory of autism, it has been proposed that deficits in the MZN underlie social impairments observed in individuals with autism (mindblindness theory; Baron-Cohen, 1995; Baron-Cohen, Leslie, & Frith, 1985; Frith, 2001), such that individuals may not spontaneously take the perspective of others (Castelli, Frith, Happé, & Frith, 2002; Kana, Keller, Cherkassky, Minshew, & Just, 2009) and thus have difficulty interpreting the intentions of others. Studies examining function of the MZN in ASD have found reduced activation (Castelli et al., 2002) or aberrant functional connectivity between these areas (Kana et al., 2015, 2009; Libero et al., 2014), compared to TD controls. When observing irrational hand-reaching actions, compared to rational reaching actions, which should engage the MZN as described above, individuals with ASD showed greater activation in the right intraparietal sulcus, an area considered part of the AON, though the TD group did as well (Marsh & Hamilton, 2011). No other areas differentiated rational from irrational actions in the ASD group. Another study examining activity in the pSTS when participants observed hand actions that were congruent or incongruent with an actor’s eye gaze and facial expression found that the pSTS in children with ASD did not differentiate between these two types of actions, while TD children exhibited greater activation to incongruent stimuli (Pelphrey, Shultz, Hudac, & Vander Wyk, 2011).

Typically developing (TD) children, from an early age, understand that human actions are goal-directed and are achieved in a rational, efficient manner (Csibra, Biró, Koós, & Gergely, 2003; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999). This requires having some understanding of the action and the end-state goal of the action, and an assumption of how those fit together. Children as young as 12-months will complete actions that they saw attempted, but not completed (Meltzoff, 1995; Nielsen, 2009), indicating they not only have an understanding of the completed action, but that they inferred that the demonstrator had a different intention (i.e. goal) than what was actually observed. Similarly, TD children are less likely to imitate actions that are seen as occurring accidentally compared to actions that are deemed intentional and necessary to completing a goal (D’Entremont & Yazbek, 2007). In both of these situations, the child responds in accord with the underlying goal, even if it differed from their visual experience.

There is some evidence that children with ASD also assume that goal-directed actions should be rational in nature (Hamilton, Brindley, & Frith, 2007; Rogers, Young, Cook, Giolzetti, & Ozonoff, 2010). When presented with the unfulfilled action imitation task described above, children with ASD, similar to TD children, performed the completed action (Aldridge, Stone, Sweeney, & Bower, 2000; Carpenter, Pennington, & Rogers, 2001), indicating they too inferred the intention of the demonstrator, and that this was different than what they actually observed. However, they also imitated acts that a demonstrator performed accidently when achieving a goal as frequently as they imitated the intended acts (D’Entremont & Yazbek, 2007). A study examining action understanding in children with and without ASD presented images of people interacting with objects and asked the children

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what the person in the photo was doing and why (Boria et al., 2009). The children with ASD correctly identified what the person was doing but had difficulty interpreting what the individual intended to do with the object unless context cues, for instance a container, which indicated the person was going to place the object into it, were provided. The position of the hand and the way in which it contacted the object did not provide sufficient information for children with ASD to determine what the person intended to do with the object. Taken together, these findings suggest that individuals with ASD may have some selective difficulties in understanding particular motor actions and the goals of those actions from the perspective of the performer.

In the current study, we sought to examine the functioning of the AON and the MZN in typically developing adolescents, and those diagnosed with ASD, when observing eating and placing actions that were either conventional or unconventional. Based on previous studies, we hypothesized that TD individuals would show greater activation in the MZN during unconventional actions compared to conventional actions. Given the behavioral findings in ASD, we hypothesized that the ASD group would be less likely to spontaneously take the perspective of and reflect upon the intentions of the actor, and therefore we would see modulation in the AON for unconventional versus conventional actions, but less activation in the MZN overall compared to the TD group.

Methods

Participants

Sixteen children and adolescents (2 females) with a clinical diagnosis of high functioning autism or Asperger's syndrome and 16 age and IQ matched TD children and adolescents (4 females) participated in the study between March of 2009 and November of 2012. Autism diagnosis was confirmed for 12 of the ASD participants by completion of the ADOS (Lord et al., 2000). An additional 19 participants were recruited for the study but were excluded due to an inability to complete the protocol (ASD $N = 4$, TD $N = 2$), or because they had more than 3.4 mm movement in the scanner (ASD $N = 7$, TD $N = 5$) or did not meet study criteria (ASD $N = 1$). Performance IQ, as assessed with the WASI (Wechsler Abbreviated Scale of Intelligence) was used as our primary IQ measure, and was not significantly different between groups. All participants had normal or corrected to normal vision. Participant details can be found in Table 1.

Participants were primarily recruited through the Subject Tracking System at the University of California Davis MIND (Medical Investigation of Neurodevelopmental Disorders) Institute. All participants were screened to exclude individuals who had a history of seizures, head trauma, pre-term birth, or who were taking anti-psychotic medications. ASD participants must not have had any other associated disorder, such as fragile X syndrome. TD participants must not have had any history of developmental delay or immediate family members diagnosed with ASD. Guardians of all participants signed an informed consent approved by the University of California Davis Institutional Review Board prior to inclusion in the study and were given minimal compensation for their participation.

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Behavioral Measures

Two questionnaires were administered to assess whether there were behavioral differences in social or motor functioning between our two groups as well as examine possible associations between neural functioning and social or motor abilities, as has been previously reported in other studies (Bastiaansen et al., 2011; Dapretto et al., 2006). The Developmental Coordination Questionnaire (DCDQ'07; Wilson et al., 2009) is designed to screen for coordinator disorders in children aged 5 to 15 years and consists of 15-items that are completed by a parent or guardian of the child. There are three subscales: control during movement, fine motor skills, and general coordination. Responses are made on a 7-point Likert scale, the maximum score being 75, with lower scores indicating difficulties with motor coordination. A score of 58 or lower suggests possible developmental coordination disorder. The Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) was administered to assess social functioning in our groups as this questionnaire is often used to screen for possible ASD through assessment of communication and social skills. This 40-item yes/no questionnaire was completed by participants' parents or guardians, with higher scores indicating difficulty with social functioning. A cut-off score of 11 or greater suggests possible ASD (Wiggins, Bakeman, Adamson, & Robins, 2007).

Data analysis

Between group differences were assessed using independent t-tests or Welch's unequal variances t-tests in situations where there was unequal variance between the groups (e.g. SCQ, DCDQ'07). Pearson correlations were conducted to examine potential individual differences between brain activity and behavioral measures. These analyses were performed using GraphPad Prism version 7.00 for Windows, GraphPad Software, La Jolla, California USA, www.graphpad.com.

Experimental design

Stimuli were videos taken of a female actor performing eating and placing actions in a conventional or unconventional manner, resulting in four conditions. Each video featured the same actor sitting at a table with the relevant item laying in the center the table. In the conventional eating (CE) condition, the actor picked up a food item and brought it to her mouth, opening her mouth approximately mid-way in the lift. Food items consisted of a: 1) carrot, 2) Tootsie Roll, 3) green apple, and 4) bagel. In the conventional placing (CP) condition, the actor picked up an inedible object located at the center of the table, lifted it and brought it across the table to a respective placing location. Item pairs in the placing condition consisted of a: 1) screwdriver and toolbox, 2) crayon and crayon box, 3) tennis ball and tennis ball container, and 4) toy ring and ring stacking post. In the unconventional conditions, the action, eating or placing, was the same, but the object that was used was from the opposite action. For example, an unconventional eating (UE) action would be the actor bringing a tennis ball to her mouth (instead of a green apple). Likewise, an unconventional placing (UP) trial would be the actor placing a green apple into a tennis ball container (see Figure 1). All videos were 4-seconds in duration and stopped before items were put in the mouth or placed completely in their final location.

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Each video was presented once over two 5.28-minute runs, for 80 total trials, 20 trials per condition. The experiment was a passive viewing event related design, with trials separated by a jittered inter-stimulus interval ranging from 2- to 8-seconds, designated by a rainbow fixation circle on a gray screen. Participants were instructed to attend to the stimuli at all times.

Image acquisition and preprocessing

Functional MR data were acquired on a 3.0T Siemens Trio scanner using a standard echo planar pulse sequence and a Siemens 8-channel head coil. The parameters for the EPI sequence were: TR = 2000 ms, TE = 30 ms, FA = 90°, FOV = 218 mm, matrix = 64 × 64 × 64, 32 axial slices, slice thickness = 3.4 mm, voxel size = 3.4 mm^3. Structural images were also acquired in the same scan session with a T1-weighted MPRAGE 3D MRI sequence (TR = 2170 ms, TE = 4.86 ms, flip angle = 7°, FOV = 256 mm, matrix = 256^2, slice thickness = 1 mm, 192 slices). Presentation™ was used to present the functional task, projected to a screen located at the participant's feet. Participants viewed the screen with a head-mounted mirror.

Data preprocessing and analysis was performed with SPM5 (Statistical Parametric Mapping, Wellcome Trust Centre for Neuroimaging, http://www.fil.ion.ucl.ac.uk/spm). The preprocessing steps included: 1) slice-timing correction, 2) realignment using cubic spine interpolation to the first non-discarded scan in a run, 3) coregistration to the MNI-transformed MPRAGE structural scan using cubic spline interpolation, 4) normalization to standard MNI space, and 5) spatial smoothing with a 5-mm full width half maximum (FWHM) Gaussian kernel. Movement for all participants included in analyses was less than 3.4 mm in x, y, or z planes.

Single subject effects were estimated using the general linear model in SPM5. Each trial was modeled with the canonical hemodynamic response function over the duration of the video. Regressors were included to account for participant head movement and signal differences across scanning runs. A high-pass temporal filter with a cut-off of 128-seconds was applied to remove low frequency drift. Second-level analyses were one- and two-sample t-tests for each contrast of interest, with participant treated as a random effect.

To observe the general pattern of activation in response to our stimulus conditions, each of the four main video conditions was assessed compared to baseline. The effect of conventionality was examined by comparing Conventional > Unconventional, regardless of action type ((CE+CP)>(UE+UP)), as well as the reverse, Unconventional > Conventional ((UE+UP)>(CE+CP)). Action type was examined by comparing Placing > Eating ((UP+CP)>(UE+CE)) and Eating > Placing ((UE+CE)>(UP+CP)).

Three masks, one for the AON, one for the MZN, and one for the STS, were created to examine activation to our conditions of interest. Ten areas were included in the AON mask, which were taken from frontal and parietal areas reported by Shaw et al. (2012) and used in our previous study examining activation in the AON of TD and ASD adolescents when observing hand movements (XXXXXXXX). These 10 areas were: inferior frontal gyrus (IFG: −50,12,22; 50,16,24), premotor cortex (PMC: −40, −2,45; 42,2,44), inferior parietal

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lobule (IPL: −42, −41,47; 37, −42,49), supramarginal gyrus/angular gyrus (SMG/AG: −58,−28,34; 50,−30,42), and superior parietal lobule (SPL: −28,−56,56; 26,−56,60). The areas included in the MZN mask included: temporoparietal junction (TPJ: −50.51, −57.92,24.15; 50.51,−57.92,24.15), and precuneus (PCC: 0,−63.84,40.16), (coordinates for both taken from van Overwalle and Baetens [2009]), and dorsal and ventral areas of the medial prefrontal cortex (dmPFC: 2,58,20; vmPFC: 0,54,−8) (Lombardo, Chakrabarti, Bullmore, & Baron-Cohen, 2011). These two masks were created using the WFU Pick Atlas, version 2.4 (Maldjian, Laurienti, Burdette, & Kraft, 2003; Maldjian, Laurienti, & Burdette, 2004), using a 5-mm (AON) or 10-mm (MZN) radius sphere around the coordinates listed above. The STS mask was a larger mask encompassing most of the temporal lobe and did have some overlap with the TPJ and SMG areas that were included in the MZN and AON masks respectively. The STS mask was also created using the WFU Pick Atlas, by selecting the following 'TD Labels': medial temporal gyrus, superior temporal gyrus, angular gyrus, and supramarginal gyrus. All the resulting SPM maps were thresholded at FDR-corrected $p<0.05$ (Genovese, Lazar, & Nichols, 2002) and an extent of 10 voxels. For analyses examining correlations of the effect of a condition with behavioral measures, mean parameter estimates (beta) were extracted from each ROI by averaging the parameter estimates of all voxels in each region using MarsBaR (http://marsbar.sourceforge.net).

Results

Behavioral Measures

Scores on the SCQ, which assesses social functioning, were significantly higher in the ASD group compared to the TD group, indicating impaired social functioning. Scores on the DCDQ'07, which assesses motor functioning, were significantly lower in the ASD group compared to the TD group, indicating poorer reported motor skills in the ASD group. Details can be found in Table 1.

Neural response to each video condition

We assessed activation in the AON, MZN, and STS while participants viewed each of the video presentations (CE, UE, CP, UP) compared to baseline to get an overall pattern of activation to the different conditions. There were no significant activations that survived correction in areas of the AON or MZN for the TD or ASD groups during either eating condition, conventional (CE) or unconventional (UE). However, there was a significant group difference (tdCE>asdCE) in areas of the MZN when viewing actions depicting conventional eating (Table 2), including the PCC, dmPFC, and bilateral TPJ (Figure 2). For the placing videos, both the conventional and unconventional placing actions significantly activated areas within the AON, but not the MZN, for both TD and ASD groups (Table 3, Figure 3). Between group comparisons (tdCP>asdCP; asdCP>tdCP; tdUP>asdUP; asdUP>tdUP) however, revealed no significant differences in any of the AON or MZN regions for either of the placing videos. As for the STS, there were significant activations in areas of the STS, specifically the posterior STS, in response to all video conditions, for both the TD and ASD groups (Table 4, Figure 4). There were no significant between group differences in the STS region for any of the video conditions.

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Effect of conventionality

To examine whether there was an effect of conventionality, regardless of the type of action, eating or placing, we compared a) conventional versus unconventional of eating and placing actions ([CE+CP] > [UE+UP]), and b) unconventional versus conventional eating and placing ([UE+UP] > [CE+CP]). The analyses comparing conventional to unconventional actions revealed no significant areas of activation in the AON, MZN, or STS in either group, TD or ASD. There were also no significant between group differences (TD>ASD: [(tdCE +tdCP)-(tdUE+tdUP)] > [(asdCE+asdCP)-(asdUE+asdUP)]; ASD>TD: [(asdCE+asdCP)-(asdUE+asdUP)] > [(tdCE+tdCP)-(tdUE+tdUP)]. The reverse condition, unconventional compared to conventional actions, was similar, with no regions of the AON, MZN, or STS showing significant activation in either group, and no between group differences.

Effect of action type

We also examined whether activation patterns in the AON, MZN, or STS differed depending on the type of action, eating or placing, portrayed in the videos. For eating compared to placing actions ([CE+UE] – [CP+UP]), no regions in the AON, MZN, or STS of either group (TD or ASD) had significant activation that survived correction. Similarly, there were no significant between group differences, either TD>ASD or ASD>TD. When comparing placing actions to eating actions ([CP+UP] > [CE+UE]), regions of the AON, including bilateral SPL, were significantly activated for both groups (Table 5). Additionally, in the ASD group, the right TPJ of the MZN and areas of the STS were significantly active (Table 5). Between group comparisons (TD>ASD, ASD>TD) however, revealed no significant differences in any of the AON, MZN, or STS regions.

Relationship between neural and social functioning, motor coordination, and age

We assessed via Pearson correlations whether in the conventional placing condition, in which we found a significant group difference in areas of the MZN, there was a relationship between neural activity in the MZN and social (SCQ) or motor (DCDQ) functioning in the ASD group. We found no significant correlations in any of the MZN areas and these behavioral measures. There was also no association between activity in these areas and age in either the TD or ASD groups.

Discussion

The current study examined whether children and adolescents diagnosed with ASD would show a different pattern of neural activation when observing conventional and unconventional goal-directed actions compared to TD children. Behavioral evidence suggests that individuals with ASD have an understanding of rules connecting particular actions and objects, such as being able to imitate familiar behavioral repertoires with familiar objects (Rogers, Bennetto, McEvoy, & Pennington, 1996). However, they may not fully appreciate the intention of the person performing the action (D’Entremont & Yazbek, 2007; Hobson & Lee, 1999; Hobson & Hobson, 2008). Neuroimaging studies have shown that the AON and MZN may reflect different aspects of actions performed by others (e.g. Spunt et al., 2011; Van Overwalle & Baetens, 2009). While typical goal-directed actions activate the AON, if the action is unusual in some way, the observer may be compelled to

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consider the intentions of the person performing the action to determine why the action is occurring, thereby invoking ToM process and thus recruiting MZN areas.

Our original hypothesis was that the MZN would be active during unconventional compared to conventional actions in the TD group. In the ASD group we hypothesized that it may be the AON differentiating conventional and unconventional actions, as opposed to the MZN. Contrary to our hypothesis, there were no areas that were significantly more active for unconventional versus conventional actions in either the TD or ASD group. One possible explanation for this is that participants passively viewed the videos and were not making explicit judgments about the actions they were observing. When participants are to *explicitly* consider the intentions of an actor, mentalizing areas typically are recruited (de Lange et al., 2008; Libero et al., 2014; Spunt et al., 2011). However, when passively viewing unusual actions, the findings are less clear, with some studies finding patterns of mentalizing activation (Brass et al., 2007; Buccino et al., 2007), while others have not (Ampe, Ma, Van Hoeck, Vandekerckhove, & Van Overwalle, 2012; Jastorff, Clavagnier, Gergely, & Orban, 2011). Anecdotally, many children, both TD and ASD, in our study remarked about the ‘odd’ actions that the person in the video was doing, but they may not have thought deeper about the actions, such as questioning *why* the person may have been performing such an odd action. Another possible explanation is that while the actions in our study were unusual, they may not have been deemed implausible (Brass et al., 2007), as the video stopped before any final action occurred, such as actually biting into the tennis ball.

It may also be that cues in the video provided enough context for participants to anticipate what the actor may do with the object. In a previous study, children looked at photos and determined a) whether the person in the photo was touching or grasping an object, and b) if grasping, whether the person was going to use the object or place the object (Boria et al., 2009). When there were no context cues provided in the pictures, the ASD children had many errors in determining grasps that were to place the object. However, when context cues were included in the photos, the ASD children performed equally to the TD children. In our study, context cues were present, such as a toolbox on the table for the object to be placed into it, even if that object was a carrot. Therefore, while participants may have thought it odd to not eat the carrot, a container was available in which to place the carrot.

Lastly, it is possible that this reflects differences in neural processing between adolescence and adulthood, as the aforementioned studies examined neurotypical adults. There is mounting evidence of continued structural and functional maturation of brain areas involved in social cognitive processes through adolescence and young adulthood (Blakemore, 2012; Burnett, Sebastian, Cohen Kadosh, & Blakemore, 2011; Dumontheil, 2016; Gunther Moor et al., 2012). While adolescents can infer the intentions of others and detect actions that are unusual, they may not show the adult pattern of increased activation of the MZN when observing unusual, compared to conventional, actions. We did examine whether there were developmental changes in activation in our two groups and did not find significant results. However, our sample size in this study was small and it would be difficult to detect a significant correlation. Future studies, particularly those that involve adolescents, should take this into account and recruit more participants in order to gain a better understanding of how these processes may change over this period of development.

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We also hypothesized, based on previous findings (Castelli et al., 2002; Kana et al., 2009), that there would be less MZN activity in the ASD group, which was partially confirmed in the present study. When observing conventional eating, but not placing, actions, the TD group had significantly greater activity in areas of the MZN, including the PCC, dmPFC, and bilateral TPJ. For one, this indicates that during some conventional actions the TD group may have been engaging the MZN, though the level of activation did not pass our threshold when examining within subjects. That said, the ASD group had significantly less activation in these areas compared to the TD group, possibly reflecting that individuals with ASD may not spontaneously attribute mental states to social stimuli (Senju, 2012; Sodian, Schuwerk, & Kristen, 2015). This also may provide partial support for other studies that have found differential functioning of the MZN in individuals with autism (Castelli et al., 2002; Kana et al., 2015, 2009; Libero et al., 2014)

An unexpected finding was that the type of action, eating or placing, portrayed in the video appeared to be encoded in areas of the AON, with placing actions significantly activating the AON compared to eating actions. In a previous study, we examined activation of the AON while TD and ASD children and adolescents observed transitive and intransitive actions that were fully or partially visible (XXXXXXXXX). In that study, a hand reached across the screen to grasp an object on the table (transitive) or where an object would be located (intransitive), and in half of the conditions (‘hidden’ conditions) an opaque screen would come across so the participants would not see the hand grasp the object (or imagined object). For transitive actions that were fully visible, we found significant activation of all regions of the AON in TD participants and in all regions except for bilateral PMC and the right SMG in ASD participants, with no significant between group differences. The placing actions in the current study would be similar to the visible transitive condition, with a person reaching to grasp an object and move it to another location. Both TD and ASD groups had significant activation in regions of the AON for these placing actions, and as in the previous study, there were no significant between group differences in any of these areas.

One might assume that eating actions, which also involved a hand reaching to grasp an object, should also result in significant activation of the AON. However, the ASD group had significant activation in most areas of the AON when specifically comparing placing versus eating actions, and the TD group also had significant activation in bilateral SPL and the right SMG. Placing actions in this study, compared to eating actions, appears to preferentially engage areas of the AON, in both TD and ASD individuals. A study by Ramsey, Cross, and Hamilton (2013), which compared cleaning and eating actions, also found greater activation to cleaning actions in dorsal frontoparietal areas, including premotor cortex and IPS, in line with our findings. Ramsey, et al., (2013) suggest that this difference may be due to the direction of motion perceived by the viewer, with greater premotor and parietal activity in response to actions in which it appears that an object is coming toward the viewer, as opposed to eating actions in which an object is going away from the observer and toward the actor. Similarly, in our study, the placing actions would appear to move more toward the observer as the objects were located out in front of the actor and thus movement to place the object in a container occurred closer to the observer than did eating actions that did move the object away from the observer. Therefore, this may explain why placing, as opposed to eating, actions preferentially engaged the AON, particularly parietal and premotor areas.

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Conclusions

In the current study, we examined the activation of two neural networks, the AON and the MZN, in ASD and TD children and adolescents while they viewed videos of people performing conventional and unconventional actions. Contrary to our predictions, neither the AON nor the MZN differentiated the conventionality of the actions in either of our groups of participants, ASD or TD. This may have been due to the fact that participants passively viewed the videos and were not asked to explicitly judge the action that was being performed nor infer the intention of the actor. While observing conventional eating actions, the TD group did have significantly greater activation than the ASD group in areas of the MZN, suggesting that TD individuals may engage the MZN during the observation of some conventional actions, which ASD individuals may not do.

While we did not anticipate significant differences in the activation of these two networks to the type of action that was portrayed, the AON did differentiate action type, with significantly greater activation to placing compared to eating actions. This differentiation was found in both of the groups, TD and ASD, and was not significantly different between them. The lack of between group differences is consistent with our previous study, which also did not find group differences in the activation of the AON while TD and ASD participants viewed transitive reaching actions (XXXXXXXX), and provides further evidence that there are not global differences in the AON of ASD.

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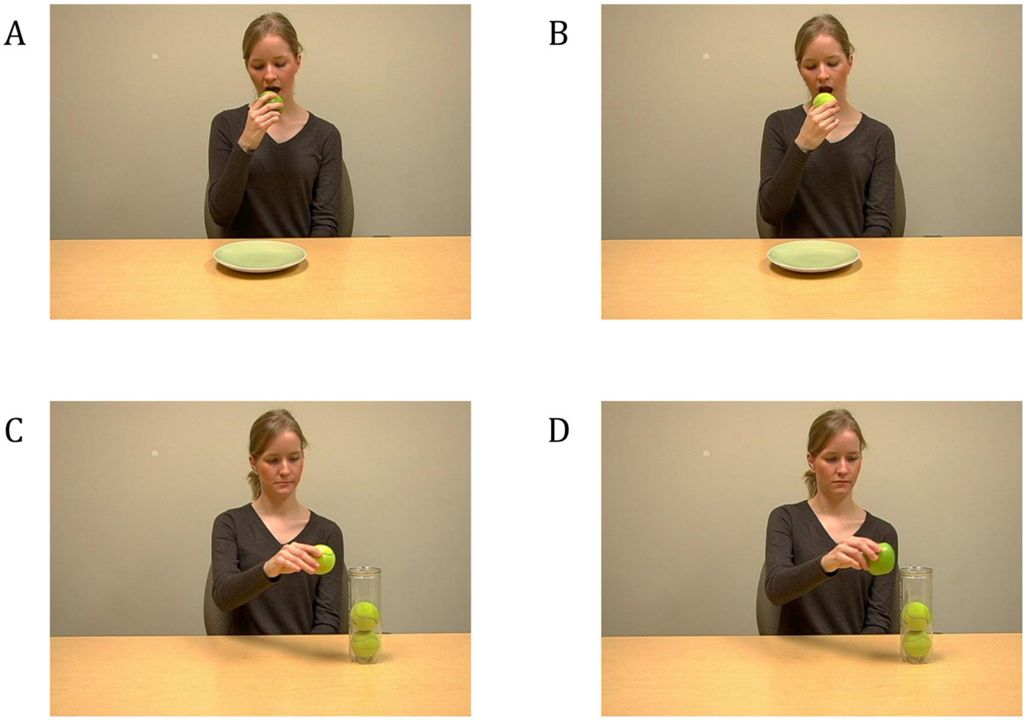

Figure 1.

Still photo taken from 4-second video examples, a) conventional eating, eating a green apple, b) unconventional eating, eating a tennis ball, c) conventional placing, placing a tennis ball into a container, d) unconventional placing, placing a green apple into a tennis ball container.

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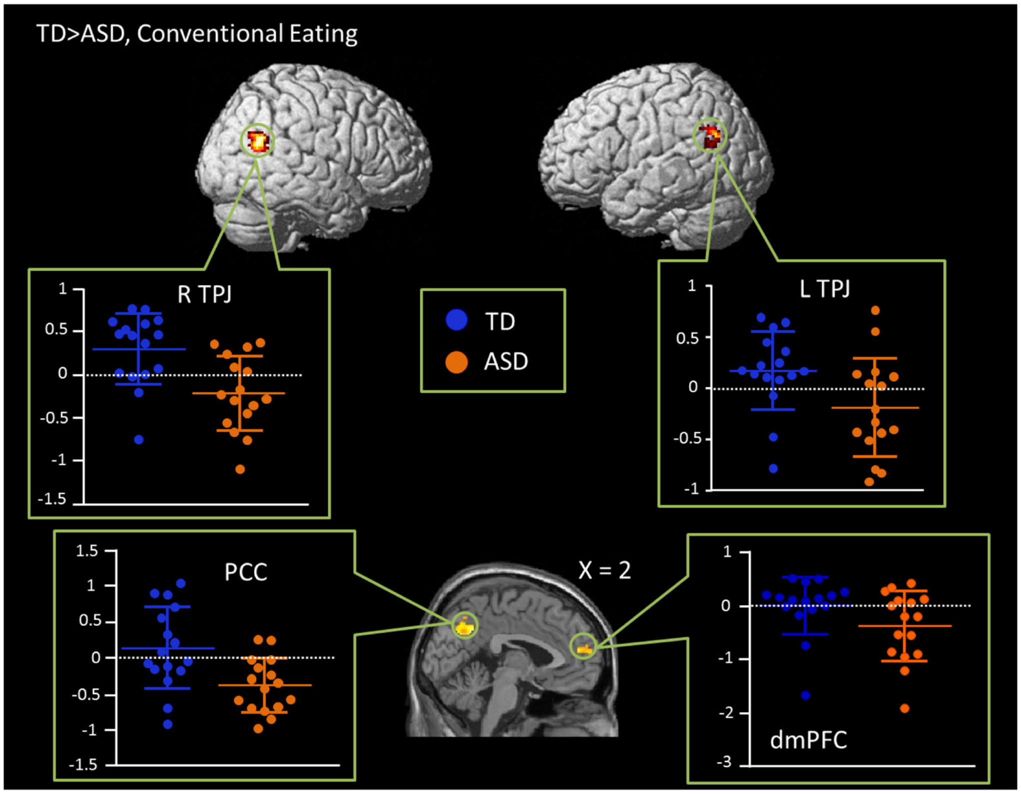

Figure 2.

Areas of activation in the MZN that were significantly greater for typically developing (TD) adolescents compared to adolescents with autism spectrum disorder (ASD) when viewing videos depicting conventional eating. Areas include bilateral TPJ, PCC and dmPFC. Individual beta values for both groups are also shown. Beta values were extracted using Marsbar by averaging the parameter estimates of all voxels in each ROI.

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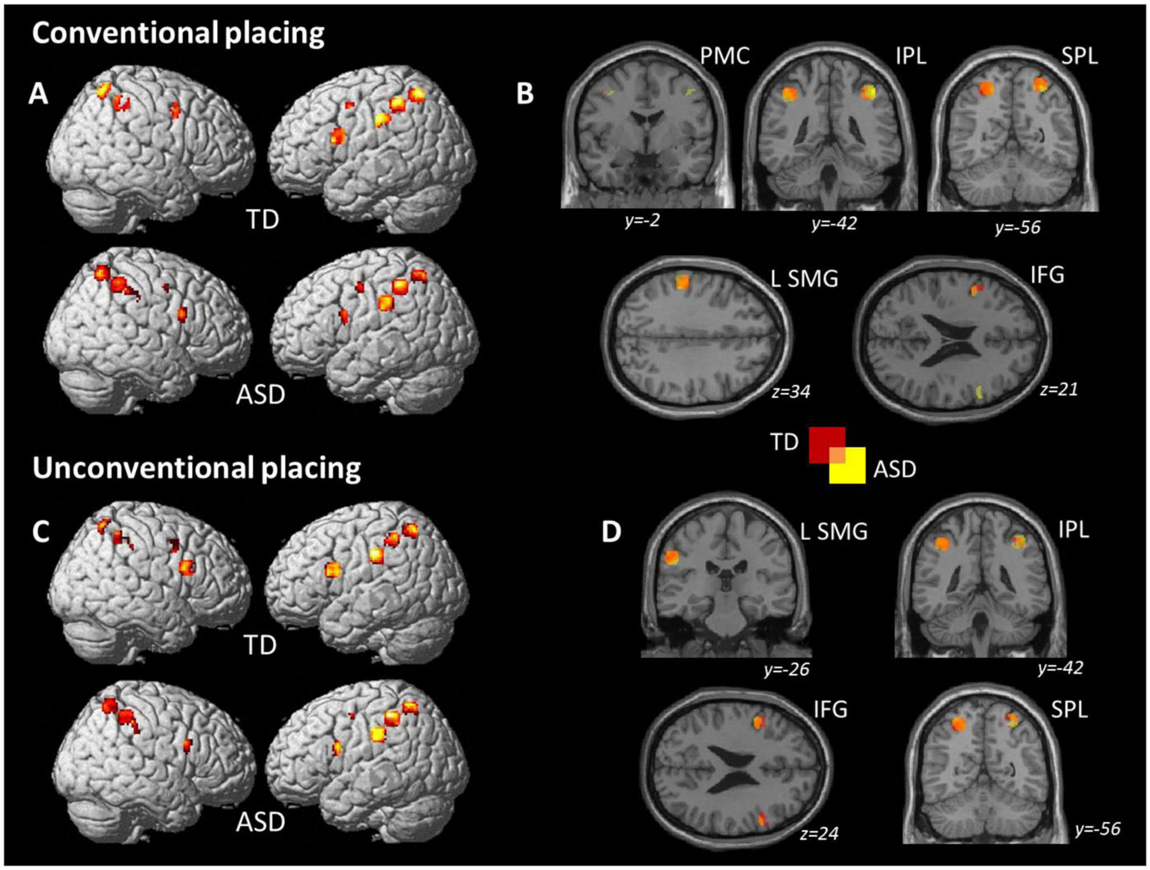

Figure 3.
Areas of activation in the AON for TD and ASD participants when viewing videos depicting conventional (A, B) and unconventional (C, D) placing actions. On the right, (B, D) areas in red represent TD activation, areas in yellow represent ASD activation, and orange indicates areas that were common between the TD and ASD groups.

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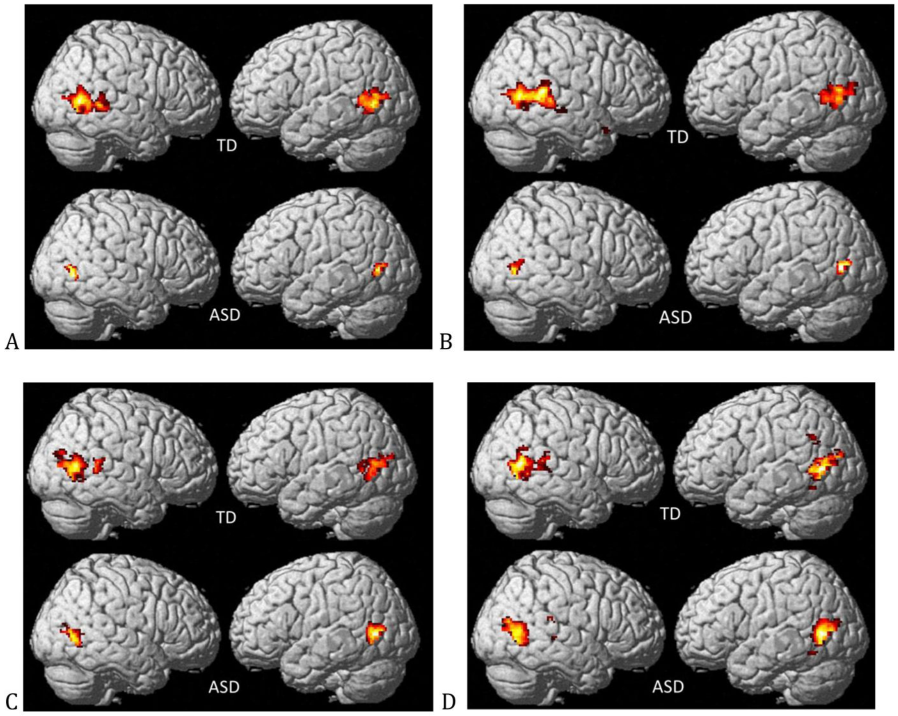

Figure 4.

Activation maps of the STS for both TD and ASD groups in response to the following video conditions: a) conventional eating, b) unconventional eating, c) conventional placing, d) unconventional placing.

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Table 1

Participants' age in years and months, Performance IQ (PIQ), and scores on the Autism Diagnostic Observation Schedule (ADOS), Social Communication Questionnaire (SCQ), and Developmental Coordination Questionnaire (DCDQ'07). The number of participants is reported (N=xx) if differed from overall total number of participants.

	TD group (N = 16		ASD group (N = 16)		
	Mean (SD)	**Range**	**Mean (SD)**	**Range**	**Significance**
Age (yr,mo)	14,2 (2,4)	9,2–17,8	14,11 (2,0)	11,7–17,7	$t(30) = 1.012$, p = NS
PIQ	110.8 (12.58), N=14	90–133	105.5 (12.60), N=13	81–126	$t(25) = 1.086$, p = NS
ADOS	NA		11.13 (2.26), N=13	7–14	NA
SCQ	1.87 (2.3), N=15	0–7	23.00 (6.78), N=14	9–34	$t(15.76) = 11.08$, $p < 0.001$
DCDQ'07	69.13 (7.75, 45–75)		45.33 (13.99), N=15	23–70	$t(21.56) = 5.80$, $p < 0.001$

Note: ADOS score is the sum (total) of the Reciprocal Social Interaction and the Communication scores

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Table 2

Group difference in regions of the mentalizing network (MZN) in response to conventional eating video condition compared to baseline. Results are shown for regions of the MZN, thresholded at a voxel-wise false discovery rate of p<0.05 and a cluster extent (k) of at least 10 voxels.

Conventional Eating > Baseline	**Region**	***t*-value**	***Z*-score**	***k***	**MNI coordinates**		
					x	**y**	**z**
TD > ASD	R Temporoparietal Junction	4.83	4.12	265	44	−56	26
	L Temporoparietal Junction	3.36	3.07	108	−52	−66	28
	Posterior Cingulate Cortex	4.50	3.90	214	4	−56	36
	Dorsomedial Prefrontal Cortex	3.76	3.38	70	4	50	16

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Table 3

Results of activation in response to placing actions: 1) Conventional Placing, and 2) Unconventional Placing. Results are shown for regions of the AON, thresholded at a voxel-wise false discovery rate of p< 0.05 and a cluster extent (k) of at least 10 voxels.

					MNI coordinates		
Contrast and group	**Region**	***t*-value**	***Z*-score**	***k***	**x**	**y**	**z**
Conventional Placing > Baseline							
TD	LInferior Frontal Gyrus	4.50	3.53	131	−56	10	24
	R Premotor Cortex	3.05	2.65	59	44	6	44
	L Premotor Cortex	3.88	3.18	23	−46	2	48
	R Inferior Parietal Lobule	4.13	3.32	158	34	−44	44
	L Inferior Parietal Lobule	5.84	4.15	205	−38	−44	50
	L Supramarginal Gyrus	5.09	3.82	149	−54	−22	34
	R Superior Parietal Lobule	4.75	3.65	170	30	−62	58
	L Superior Parietal Lobule	5.95	4.20	232	−24	−62	60
ASD	R Inferior Frontal Gyrus	4.40	3.47	90	52	12	30
	LInferior Frontal Gyrus	4.01	3.25	81	−50	6	26
	R Premotor Cortex	2.91	2.55	20	44	−2	50
	L Premotor Cortex	4.34	3.44	59	−40	−6	46
	R Inferior Parietal Lobule	6.62	4.46	318	44	−40	52
	L Inferior Parietal Lobule	6.47	4.50	265	−42	−38	50
	L Supramarginal Gyrus	4.48	3.51	253	−56	−28	34
	R Superior Parietal Lobule	4.97	3.76	211	30	−60	60
	L Superior Parietal Lobule	5.24	3.89	251	−22	−58	56
Unconventional Placing > Baseline							
TD	R Inferior Frontal Gyrus	3.84	3.15	183	50	16	18
	L Inferior Frontal Gyrus	4.64	3.60	241	−48	6	20
	R Premotor Cortex	3.07	2.66	33	48	6	40
	R Inferior Parietal Lobule	3.84	3.15	137	40	−46	54
	L Inferior Parietal Lobule	5.52	4.02	188	−38	−44	54
	R Supramarginal Gyrus	2.57	2.30	12	46	−32	42

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Contrast and group	Region	*t*-value	*Z*-score	*k*	MNI coordinates x	y	z
ASD	L Supramarginal Gyrus	5.01	3.78	204	−54	−24	40
	R Superior Parietal Lobule	3.36	2.86	112	20	−58	62
	L Superior Parietal Lobule	5.75	4.12	223	−32	−50	52
	R Inferior Frontal Gyrus	4.25	3.39	59	52	10	28
	L Inferior Frontal Gyrus	3.95	3.22	109	−54	6	24
	L Premotor Cortex	2.81	2.48	19	−40	−6	52
	R Inferior Parietal Lobule	3.92	3.20	286	42	−38	54
	L Inferior Parietal Lobule	6.43	4.39	266	−42	−38	52
	L Supramarginal Gyrus	5.08	3.81	253	−54	−24	40
	R Superior Parietal Lobule	3.59	3.00	145	32	−60	60
	L Superior Parietal Lobule	4.89	3.72	244	−30	−50	54

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Table 4

Areas of peak activation in the STS for each video condition: 1) Conventional Eating, 2) Unconventional Eating, 3) Conventional Placing, 4) Unconventional Placing. Results are thresholded at a voxel-wise false discovery rate of p<0.05 and a cluster extent (k) of at least 10 voxels.

					MNI coordinates		
Contrast and group	**Region**	***t*-value**	***Z*-score**	***k***	**x**	**y**	**z**
Conventional Eating> Baseline							
TD	L Middle Temporal Gyrus	9.24	5.27	707	−44	−64	2
	R Middle Temporal Gyrus	8.67	5.11	1007	44	−60	4
ASD	R Middle Temporal Gyrus	6.98	4.59	122	50	−67	0
	L Middle Temporal Gyrus	6.37	4.37	114	−44	−72	4
Unconventional Eating> Baseline							
TD	R Superior Temporal Gyrus	9.48	5.33	1540	64	−42	10
	L Middle Temporal Gyrus	7.15	4.65	727	−46	−66	2
ASD	L Middle Temporal Gyrus	7.13	4.64	155	−50	−74	8
	R Middle Temporal Gyrus	5.75	4.12	103	50	−68	4
Conventional Placing> Baseline							
TD	R Middle Temporal Gyrus	6.70	4.49	665	44	−62	2
	L Middle Temporal Gyrus	6.36	4.36	487	−40	−74	12
	R Superior Temporal Gyrus	6.29	4.34	154	52	−40	4
	R Middle Temporal Gyrus	4.34	3.44	58	36	−72	20
ASD	L Middle Temporal Gyrus	9.39	5.30	345	−42	−64	0
	R Middle Temporal Gyrus	6.48	4.41	258	52	−68	4
Unconventional Placing> Baseline							
TD	L Middle Temporal Gyrus	8.82	5.16	558	−44	−64	−4
	R Middle Temporal Gyrus	7.28	4.69	618	44	−64	0
	R Superior Temporal Gyrus	4.91	3.73	118	56	−34	14
	L Middle Temporal Gyrus	4.86	3.71	11	−50	−58	−14
	L Angular Gyrus	4.21	3.37	26	−50	−58	34
ASD	L Middle Temporal Gyrus	10.59	5.59	645	−42	−64	0

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Contrast and group	Region	*t*-value	*Z*-score	*k*	MNI coordinates x	 y	 z
	R Middle Temporal Gyrus	7.17	4.66	716	50	−66	4
	L Middle Temporal Gyrus	6.10	4.26	12	−50	−56	−14
	R Superior Temporal Gyrus	5.15	3.85	14	50	−30	2
	R Superior Temporal Gyrus	3.78	3.12	15	60	−36	18

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Table 5

Areas of peak activation in the AON and STS for effect of action type (Placing > Eating). Results are thresholded at a voxel-wise false discovery rate of p<0.05 and a cluster extent (k) of at least 10 voxels.

					MNI coordinates		
Contrast and group	**Region**	***t*-value**	***Z*-score**	***k***	**x**	**y**	**z**
Placing > Eating							
TD	L Supramarginal Gyrus	3.89	3.18	21	−52	−26	38
	R Superior Parietal Lobule	5.23	3.89	147	22	−58	62
	L Superior Parietal Lobule	5.10	3.83	102	−24	−62	60
ASD	R Inferior Frontal Gyrus	6.23	4.31	74	54	10	28
	R Premotor Cortex	3.59	3.00	43	40	−4	44
	L Inferior Parietal Lobule	3.45	2.92	50	−38	−38	54
	R Supramarginal Gyrus	6.71	4.49	453	46	−36	42
	L Supramarginal Gyrus	2.88	2.53	18	−56	−22	38
	R Superior Parietal Lobule	5.62	4.06	245	28	−62	60
	L Superior Parietal Lobule	7.20	4.67	221	−22	−52	58
	R Temporoparietal Junction	4.83	3.69	69	50	−60	24
	R Middle Temporal Gyrus	6.97	4.59	355	34	−74	18
	L Middle Temporal Gyrus	6.37	4.37	96	−40	−84	16
	L Angular Gyrus	4.81	3.68	19	−42	−80	30