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ORIGINAL PAPER

Spatial Transformations of Bodies and Objects in Adults with Autism Spectrum Disorder

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Abstract Previous research into autism spectrum disorder (ASD) has shown people with autism to be impaired at visual perspective taking. However it is still unclear to what extent the spatial mechanisms underlying this ability contribute to these difficulties. In the current experiment we examine spatial transformations in adults with ASD and typical adults. Participants performed egocentric transformations and mental rotation of bodies and cars. Results indicated that participants with ASD had general perceptual differences impacting on response times across tasks. However, they also showed more specific differences in the egocentric task suggesting particular difficulty with using the self as a reference frame. These findings suggest that impaired perspective taking could be grounded in difficulty with the spatial transformation used to imagine the self in someone else's place.

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Introduction

Spatial transformations are the process we use to align different three dimensional representations with each other across variations in position and orientation. These transformations can contribute to social interaction because they allow us to imagine our own body in the place of another person's body (Michelon and Zacks 2006). By transforming ourselves to a different point in space it becomes possible to judge what is on another person's left or right, or to make predictions about how things may appear from a different visual perspective.

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterised by deficits in social communication and restricted interests (Wing and Gould 1979). Recent research has suggested that alongside impairments in understanding other's mental states (Baron-Cohen et al. 1985; Frith and Frith 2007; Frith 2012; Senju 2012), people with ASD also have difficulty with taking another person's visual perspective (Hamilton et al. 2009). Hamilton and colleagues found that whilst children with autism were impaired at visual perspective taking (VPT), they showed unimpaired performance on a task involving a non-social spatial transformation (mental rotation). Other studies have also linked spatial and social cognitive abilities in typical participants (Clements-Stephens et al. 2013; Surtees et al. 2013). Here we consider in more detail the spatial transformations which underlie VPT (Surtees et al. 2013; Yu and Zacks 2010) and whether these may be impaired in people with autism.

Two different types of spatial transformation—egocentric transformations and mental rotation—are the focus of

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the current study (Fig. 1). Egocentric (or 'self-based') transformations are used when we transform our own body as a whole into alignment with a new position in space (Zacks et al. 1999). Egocentric transformations contribute to VPT, because they allow a person to place themselves in another's location, and then to imagine what another person can see from a different viewpoint (Steggemann et al. 2011; Surtees et al. 2013; Yu and Zacks 2010). However, VPT requires the additional step of considering what the other can see, after the egocentric transformation (Surtees et al. 2013).

Mental rotation (or 'object based' transformation) is the process by which we can manipulate the orientation of objects in our minds (Shepard and Metzler 1971; Wraga et al. 2003). For example, we can mentally transform one external object until it corresponds with another object to determine if they are the same. Though mental rotation could be used to take another person's perspective (by rotating the whole visual scene), it is a much less efficient way of doing so compared to an egocentric transformation (Zacks and Tversky 2005).

Hamilton et al. (2009) examined VPT and mental rotation in children with autism compared to a group of verbal mental age (VMA) matched typically developing (TD) children. In the VPT task children were shown a toy which was covered with a pot. They were then asked to identify the view that a doll would have of the toy from different points on a table. In the mental rotation task the toy and the covering pot were rotated and the child was asked which view of the toy they would see when the pot was lifted. Results showed that the children with ASD were significantly less accurate on the VPT task compared to the typical children, but more accurate on the mental rotation task. One possible explanation for this discrepancy could be differences in the ability to perform egocentric transformations in the VPT task which are not required for the mental rotation task (Pearson et al. 2013). The current study explores this by examining both mental rotation and

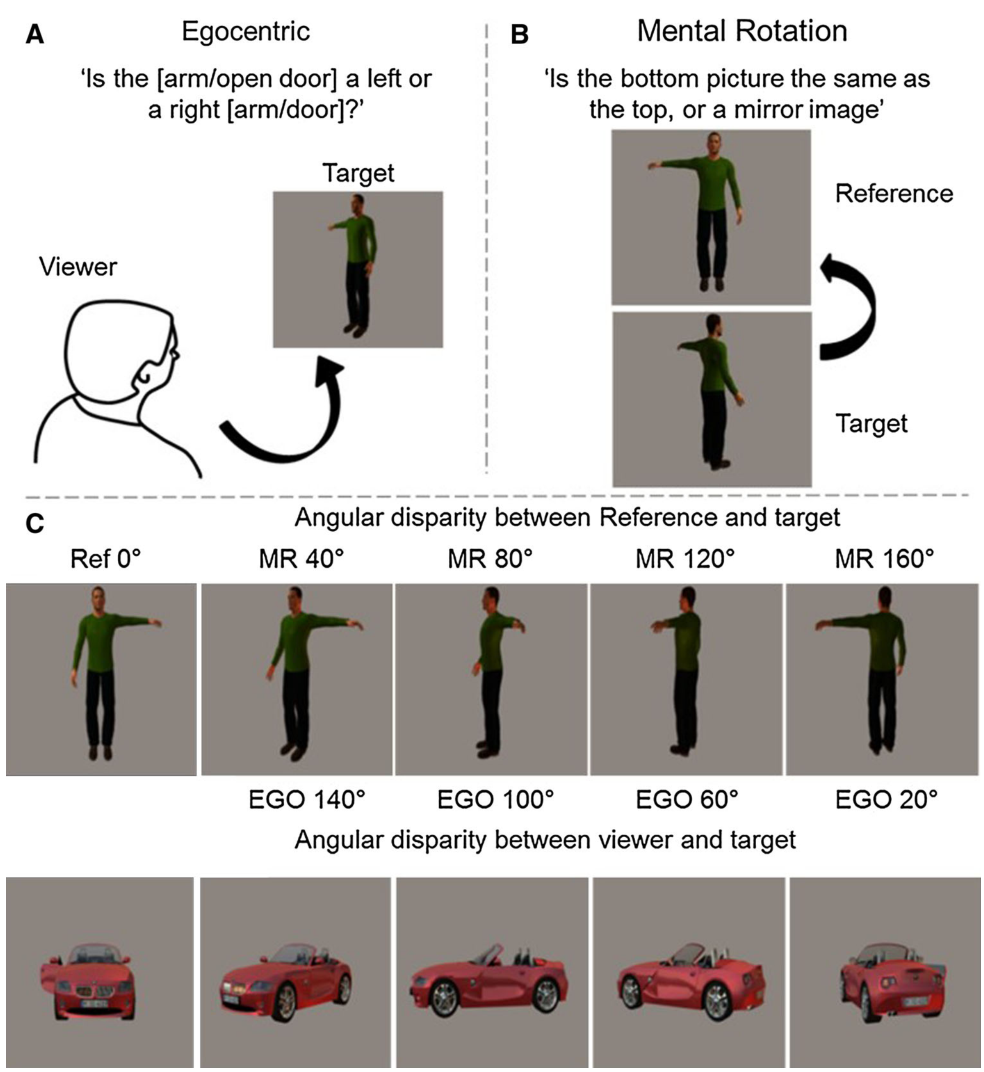

Fig. 1 Tasks and stimuli. **a** In the egocentric task, participants see one image on the screen and must judge if the extended arm/door is a *left* or *right* arm/door. This involves relating the participant's own body to the image on the screen (*black arrow*). **b** In the Mental rotation task, participants see two images on the screen and must judge if the lower (test) image shows the same figure as the upper (*reference*) image. This involves relating the two figures to each other (*black arrow*). **c** Sample car and body stimuli are shown. Mental Rotation values—the angular disparity between the reference and test image when each of these stimuli was used in the mental rotation task. EGO values—the angular disparity between the test image and the participant when each of these stimuli was used in the egocentric task

egocentric transformations in adults with autism. First, we review previous studies of spatial transformations in autism.

Egocentric Transformations

The ability to make use of egocentric transformations is typically measured using laterality judgements. In an early study, Parsons (1987) presented participants with images of bodies which had one extended limb (i.e. an outstretched arm). These images were rotated through various angular disparities. Participants were required to make a laterality judgement about the extended limb (i.e. '*is the extended arm a left or a right arm*'). Results showed that the larger the angular disparity between the body of the participant and the target body, the longer the participant took to respond. This relationship between response time and angular disparity suggests that participants performed an imagined whole body transformation in which they mentally aligned themselves with the target. These findings have been replicated numerous times since in a variety of studies on egocentric transformations (Schwabe et al. 2009; Wraga et al. 2005; Zacks et al. 1999). Similar results are found when making judgements about the location of another item in relation to a person (e.g. is the flower on his left or his right) (Kessler and Thomson 2009), and the propensity to make egocentric transformations is modulated by the social cues in the image such as gaze direction (Mazzarella et al. 2012).

There has been some investigation of egocentric transformations using laterality judgements in people with autism. David et al. (2010) examined perspective taking in high functioning adults with ASD compared to age and IQ matched TD adults. Participants were presented with images of an avatar with one object placed at each side. One of the objects was elevated and participants were instructed to determine which object was elevated using a laterality judgement (i.e. '*the item on my right is higher*'). Participants were asked to make this judgement from their own point of view or from the avatar's point of view. Results showed no significant differences in regards to response time *or* accuracy between the ASD and TD groups, suggesting no differences in egocentric transformation abilities. However, in this study the avatar was always placed directly opposite the participant, so it would be possible to answer correctly using the heuristic 'his right is my left'. This makes it hard to determine if participants were really using an egocentric transformation.

A different approach has been to link egocentric transformation ability to autistic traits within the typical population. Kessler and Wang (2012) examined a group of TD participants using the task described in Kessler and Thomson (2009). A measure of autistic traits in these participants was taken using the AQ [Autism Quotient, (Baron-Cohen et al. 2001)]. The authors found that participants with higher levels of autistic traits displayed difficulty with performing egocentric transformations and were more likely to rely on an object focused rotation strategy. Brunye et al. (2012) used a similar method to Kessler, presenting participants with an avatar seated at a table. A light appeared to either side of the avatar and the participant had to make a laterality judgement as to whether the light was on the participant's right or left side. Brunye and colleagues also used the AQ to measure autistic traits in the participants and found that those who had higher levels of autistic traits were slower to perform egocentric transformations than low AQ scorers.

The results of these studies suggest that people with autism or high levels of autistic traits may find egocentric transformations difficult. Thus, we predict that in the current study adults with autism will show impaired performance on the egocentric task compared to TD adults.

Mental Rotation

Mental rotation is the ability to imagine how an object can change orientation in space, and is typically examined using the classic same/different judgement task (Shepard and Metzler 1971) seen in Fig. 1b. Participants are presented with two objects (one reference object and another target object rotated through various orientations) and must determine if they are the same. Like egocentric transformations, mental rotation displays a linear relationship between angular disparity and response time (Shepard and Metzler 1971). The time taken to mentally rotate an object is comparable to the time it would take to physically transform an objects position, and this rotation time can be calculated from the slope of the regression fit between angular disparity and response time. Typically developing people perform mental rotation configurally, rotating the target stimulus in its current configuration as a whole into alignment with the reference stimulus. They can then compare the reference and target to decide whether they are the same. This has been shown to be the case across a variety of objects such as letters and geometric shapes (Kosslyn et al. 1998).

Several studies have shown that people with ASD appear to have intact mental rotation ability (Falter et al. 2008; Hamilton et al. 2009; Soulieres et al. 2011). Falter et al (2008) used Shepard and Metzler's mental rotation task with typical and autistic children. They found that children with autism were quicker to make the initial decision about whether two stimuli were the same or different than age matched typical children. However there were subtle differences between groups which suggested that ASD participants may have been matching across surface features (the salient features of a stimulus such as a limb on a body) instead of performing a full rotation. In this strategy participants choose a salient feature and then compare its position across the two stimuli in order to perform a match. Support for reliance on surface feature processing in ASD comes from Soulieres et al. (2011), who examined mental rotation of geometric shapes, hands and letters in adults with ASD. They found that ASD participants showed faster and more accurate performance than TD participants on all stimulus types. However results also suggested that the participants with ASD had used the surface features of the stimuli during the task as opposed to performing an holistic rotation. These differences in the performance of mental rotation in autism have been attributed to weak central coherence (WCC) (Happe and Frith 2006). The theory of WCC suggests that people with autism tend to focus more on the local features of a stimulus, in contrast to the configural or holistic processing style seen in TD people. Based on these previous studies, it is unclear how participants with ASD will perform in the mental rotation task. If they are able to perform mental rotation by engaging a detail-oriented rather than holistic strategy we may expect to see a different patterns of response times (for example, they may not show the same linear relationship between response time and angular disparity that is usually seen in TD participants, but still display similar performance in regards to accuracy). However if mental rotation is intact in autism (i.e. through the use of a configural processing approach) then we would not expect significant differences in regards to reaction times or accuracy.

The Current Study

The current study examines mental rotation and egocentric transformations in matched groups of typical adults and adults with ASD. We use a 2 × 2×2 × 4 factorial design looking at the effects of task (egocentric/mental rotation), group (ASD/Typical), stimulus form (body/car) and angular disparity (4 levels). Egocentric transformations are measured using laterality judgements (Fig. 1a) and mental rotation is measured using a standard same/different (Fig. 1b) mental rotation paradigm (Shepard and Metzler 1971). In the egocentric task the participants must decide whether an extended feature of the stimulus is a left/right feature (i.e. a right arm). Here, angular disparity is calculated in relation to the disparity between the viewer and the target (Fig. 1a). In the mental rotation task (Fig. 1b) the participant decides whether the target stimulus is the same as, or a mirror image of the reference stimulus. Here, angular disparity is calculated between the reference stimulus and the target stimulus. The paradigm used in the current study is similar to that used in Zacks et al. (2000).

Both of our tasks use the same stimuli: a fully clothed human body with one extended arm and a car with an open door. Previous studies of egocentric transformations have used mostly bodies as stimuli (Parsons 1987; Zacks et al. 1999) whereas studies of mental rotation have mostly used objects and geometric shapes (Shepard and Metzler 1971). The use of matched stimuli across both tasks is important for two reasons. Firstly it allows us to ensure that any task differences are not a result of using different stimuli across tasks. Secondly, it allows us to ensure that any differences between groups are not simply a result of perceptual processing issues in the participants with autism. It has been argued that people with autism may be impaired at the processing of bodies compared to objects (Reed et al. 2007). Thus, by testing both bodies and objects in the mental rotation and egocentric tasks we can examine difficulties which are specific to both task and stimuli. If people with autism have particular difficulty with one type of stimuli then this will be shown in a group by form interaction within the task.

We can quantify performance on our tasks in several ways. Accuracy rates and reaction times give an overall measure of performance. We also conduct a regression analysis to examine the relationship between the angular disparity in the stimulus and the reaction time. In this analysis, the *slope* parameter reveals how long it takes participants to perform the actual spatial transformation in the task, rotating their body or the object in mental space. For example, reaction times might increase by 3 ms for every additional degree of rotation required. The *intercept* parameter reveals how long it takes participants to perform all the non-spatial aspects of the task, such as visual processing of the stimulus and making a decision on the result of the mental rotation. We can thus interpret our data in terms of both spatial and non-spatial processes, as demonstrated by Falter et al. (2008).

If participants with ASD have specific problems with transforming their own body in space, then we will expect to see impaired performance on the egocentric task compared to the mental rotation task. If the ASD participants have a general problem with spatial transformations then we will see impaired performance on both the egocentric and mental rotation tasks.

Method

Participants

Two groups of participants took part in this study. Eighteen adults with a diagnosis of ASD were recruited from schools, colleges, service providers and a participant database held by the autism research team at the University of Nottingham. They had a mean age of 19.7 years and 17 were male. All individuals with ASD had an independent previous diagnosis autism or ASD and they also completed module IV of the Autism Diagnostic Observation Schedule with a trained examiner [ADOS (Lord et al. 1989)]. Four of the ASD participants did not meet cut-off for ASD on the ADOS; however as all had a previously confirmed independent diagnosis of autism or ASD they were included in the study. The comparison group consisted of eighteen typically developing participants. The typically developing participants were also recruited from schools and colleges. They had a mean age of 18.5 years and 17 were male. All participants completed the Autism Spectrum Quotient [AQ (Baron-Cohen et al. 2001)]. An independent samples t-test was used to examine whether groups differed significantly in regards to AQ scores. As expected the ASD group had significantly higher AQ scores than the TD group ($t(34) = 4.55$, $p < 0.001$). The Wechsler Adult Intelligence Scale (WAIS-IV: [Wechsler 1981)] was used to assess participants' cognitive ability (Full scale IQ, or FSIQ). There was no significant difference between the groups on this factor ($t(34) = -0.362$, $p = 0.355$). Participants from both the ASD and typically developing groups met criteria for the experiment if they had a FSIQ of 70 or above and were aged 16 plus (Table 1). Participants were matched on age, gender and FSIQ (see Table 1). Five additional ASD participants completed the WAIS but were not included in the experiment as they failed to meet the cut-off point for inclusion. Only ASD participants with higher cognitive abilities were included as we were interested in reaction time data, which is more difficult to collect in participants with impaired cognitive abilities. Data on comorbidity was not available for these participants. All participants in this study had normal or corrected to normal vision. This study was approved by the University of Nottingham ethics committee and all participants gave written informed consent prior to participating. All participants were compensated for their time.

Table 1 Descriptive statistics for each group reported as mean ± SD (range), with *t* test results for group comparisons

	ASD	TD	*T* test result
N	18	18	
Age	19.77 ± 4.95 (16–32)	18.44 ± 3.43 (16–29)	$t(34) = .939$, $p = 0.532$
FSIQ	97.61 ± 19.11 (70–132)	101.55 ± 18.33 (76–139)	$t(34) = -.632$, $p = 0.355$
AQ	26.5 ± 6.98 (17–40)	16.61 ± 6 (10–27)	$t(34) = 4.55$, $p = 0.000$
ADOS	10.6 ± 4.24 (4–18)	–	–

Design

A 2 × 2 × 2 × 4 mixed design was used, with independent variables of task (egocentric and mental rotation), group (ASD and typical), stimulus form (body and car) and angular disparity (four levels in each task). We measured the effect that these variables had upon accuracy (percentage correct) and response time (RT) in milliseconds. Each task had two blocks and each block consisted of 96 trials. Both order of task and block were counterbalanced across participants and order of trials within a block was randomised using the experimental software. The experiment was presented using Cogent (Wellcome Lab of Neurobiology) via Matlab 6.5 (Mathworks Inc.), which was used to collect and store the data.

Stimuli

The stimuli used in this study were images of a fully clothed male body and a car, which were created using Poser 6. Each stimulus was depicted at 8 possible orientations (Fig. 1c), varying in 40° increments from 40° to 160° clockwise and counter clockwise. Angular disparity in the mental rotation task was between the reference stimulus (which faced the participant) and the target stimulus. This gave angular disparities of ±40°, 80°, 120° and 160° in the mental rotation task. In the egocentric task, angular disparity was calculated between the participant's own body (180° compared to the reference stimulus in Fig. 1c) and the stimulus (Fig. 1a). This gave angular disparities of ±20°, 40°, 100° and 140° (i.e. participant at 180°—stimulus rotated by 40°, Fig. 1c) in the egocentric task. Both images were 250 × 250 pixels. In keeping with previous research (Zacks et al. 2002) the body had either the left or right arm extended in each picture, and the car had the left or right door open. There were 16 body and 16 car stimuli (8 right and 8 left, one of each angular disparity). In the mental rotation task, there were 4 additional stimuli, two forward facing bodies and cars (one right, one left per stimulus type).

Procedure

Participants were tested individually either in the University lab, or a quiet area of their school/college. Testing was split into multiple sessions due to length (experimental tasks plus ADOS and WAIS). The WAIS and ADOS were completed first and then experimental data was collected in a separate session. For the experimental tasks, all participants were seated in front of a computer screen at a distance of around 52 cm. Prior to the beginning of each task, participants were presented with a set of PowerPoint instructions detailing how to complete the task, then they completed a set of 20 practice trials with feedback to ensure that they understood instructions. After they had completed the practice trials and understood the task they began the experimental trials.

In the egocentric task, participants had to make a decision about whether an extended arm/open door on the man/car was a left or a right arm or door (Fig. 1a). One picture was presented on the screen with the angular disparity between the participant and the stimulus in the picture varying in 40° increments from 20° to 140° clockwise and counter clockwise. Participants pressed '1' to answer left (with their left hand) and '9' to answer right (with their right hand) on the number line of the keyboard. After the image had appeared on screen, participants had a maximum of 10 s to respond. The picture disappeared after the participant had made a response or the allotted trial time (10 s) had ended. The next image would then appear on the screen. No feedback was provided on the experimental trials.

In the mental rotation task participants had to make a same/different judgement about pairs of stimuli (Fig. 1b). Two pictures were presented on the screen; the top picture was a reference which always showed a car/body in a forward facing position and the bottom picture showed the same item at varying degrees of angular disparity (between 40–160° clockwise and counter clockwise in 40° increments). Participants responded by pressing '1' if the pictures were the same and '9' if they were different on the number line of the keyboard. Keys were labelled during the experiment to avoid confusion. Timing was the same as the egocentric task.

Participants completed two blocks in each task to cover the four combinations—egocentric/mental rotation and cars / bodies. Task order was counterbalanced across participants as was the order in which blocks were presented. Each block took around four minutes to complete, with breaks between blocks as necessary.

Data Analysis

Accuracy scores were computed by calculating how many correct trials each participant performed for each form/angular disparity and converting this into a percentage. Correct scores were collapsed across equivalent clockwise and counter clockwise disparities to give one value (i.e. trials for orientations +40° and −40° were combined into one variable) and then the mean value across trials calculated. Accuracy data was analysed using a mixed design repeated measures ANOVA with group as a between subjects factor.

Response times were calculated by finding the median reaction time (on correct trials only) for each participant for each angular disparity and form. We used median values to reduce the impact of outliers. To calculate the value for each angular disparity we collapsed across equivalent clockwise and counter clockwise disparities (i.e. trials for orientations +20° and −20° were combined into one variable). Response times were analysed using a mixed design repeated measures ANOVA with group as a between subjects factor. Where sphericity has been violated Greenhouse Geisser corrected values are reported.

As described previously, we can further characterise performance by examining the slope and intercept of the regression between angular disparity and reaction time (Falter et al. 2008). Slopes are related to the spatial transformation process, a positive, steeper slope indicates that at that response time is strongly affected by angular disparity. Intercepts are related to non-spatial processes such as perception and decision making. A linear regression model was fit to the reaction time data for each participant with angular disparity entered as the independent variable and the slope and intercept of the regression recorded for each task. Additionally, a mixed ANOVA was used to examine the effects of form and group on slope and intercept across tasks.

Results

Mental Rotation Results

A summary of results from all mental rotation analyses can be seen in Table 4. For accuracy, a repeated measures ANOVA showed that there was no significant effect of group or form. There was a significant effect of angular disparity [$F(3,102) = 5.86$, $p < 0.001$, $\eta^2 = 0.147$] and a significant interaction between form and angular disparity [$F(3,102) = 3.72$, $p = 0.014$, $\eta^2 = 0.099$] showing that accuracy decreased as angular disparity increased for the body stimuli but stayed stable for the car (Fig. 2b). This suggests that mental rotation of bodies is harder at higher angular disparities. All other two and three-way interactions were non-significant.

A repeated measures ANOVA examining median response times in the mental rotation task revealed that there was a marginal effect of group on RT [$F(1, 34) = 4.52$, $p = 0.054$, $\eta^2 = 0.105$], with the ASD group showing marginally slower RT's (Fig. 2a, the ASD group are represented by the black lines). There was no significant effect of form however there was a significant effect of angular disparity [$F(2.27, 77.21) = 10.9$, $p < 0.001$, $\eta^2 = 0.243$], with RT's increasing as the angular disparity between the two stimuli increased. There was also a significant interaction between group and angular disparity [$F(3,102) = 3.09$, $p = 0.03$, $\eta^2 = 0.083$] with the ASD group more strongly affected by increases in angular

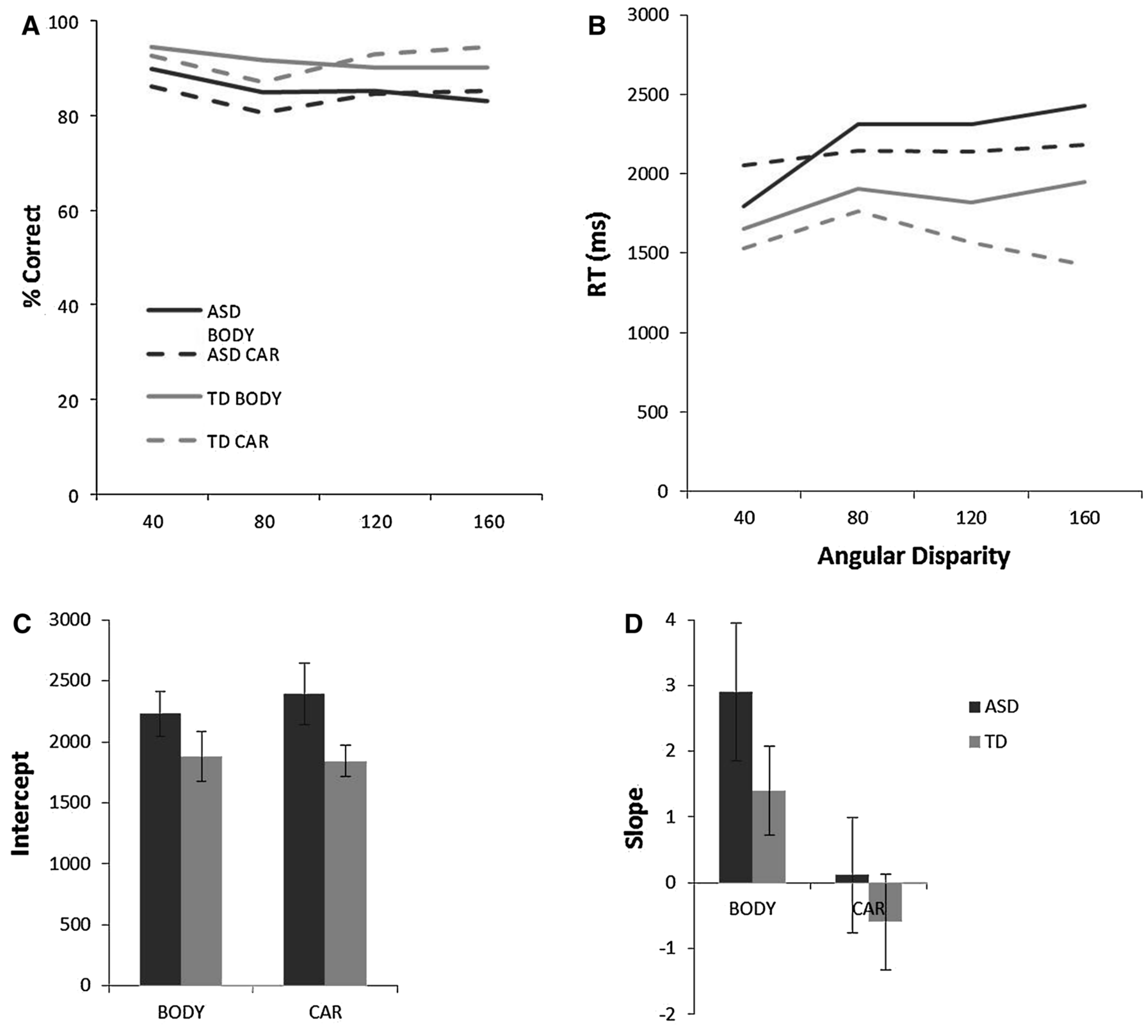

Fig. 2 In all plots the *black lines/columns* represent the ASD group and the *grey lines/columns* represent the TD group. In the upper plots the *solid lines* display performance on the body stimuli and the *dashed lines* display performance for the car. **a** Displays the effects of angular disparity on accuracy. **b** Displays effect of angular disparity on RT in the mental rotation task for ASD and TD groups' performance on the body and car. **c** Displays effects of group and form on intercepts, and **d** displays effects of group and form on slope

disparity than the typical group and a significant interaction between form and angular disparity [$F(3,102) = 7.55$, $p < 0.001$, $\eta^2 = 0.182$], with a stronger linear relationship between angular disparity and RT for the body stimuli than for the car (Fig. 2a, the car stimuli are represented by the dashed lines). All other two and three-way interactions were $p > 0.10$.

Slopes and intercepts in the mental rotation task were each examined using a repeated measures ANOVA with group entered as a between subjects factor (Fig. 2c, d, the ASD group are represented by the black columns). There was no significant effect of group however there was a significant effect of form [$F(1, 34) = 15.19$, $p < 0.001$, $\eta^2 = 0.309$] with bodies showing more positive slopes than cars. This is reflected in the interaction between form and angular disparity for response times. There were no interactions between group and form. For intercepts there was a marginal effect of group [$F(1, 34) = 3.58$, $p < 0.067$, $\eta^2 = 0.095$] with the typical group showing marginally lower intercepts than the ASD group. There were no further significant effects or interactions found in this analysis.

Egocentric Results

A summary of all results from the egocentric task can be seen in Table 4. For accuracy, a repeated measures ANOVA showed that there was a significant effect of group [$F(1, 34) = 5.91$, $p = 0.038$, $\eta^2 = 0.120$] with the ASD group less accurate than the typical group. There was no significant effect of form however there was a significant effect of angular disparity [$F(1.92, 65.42) = 23.81$, $p < 0.001$, $\eta^2 = 0.412$] with accuracy increasing as angular disparity between the participant and stimuli

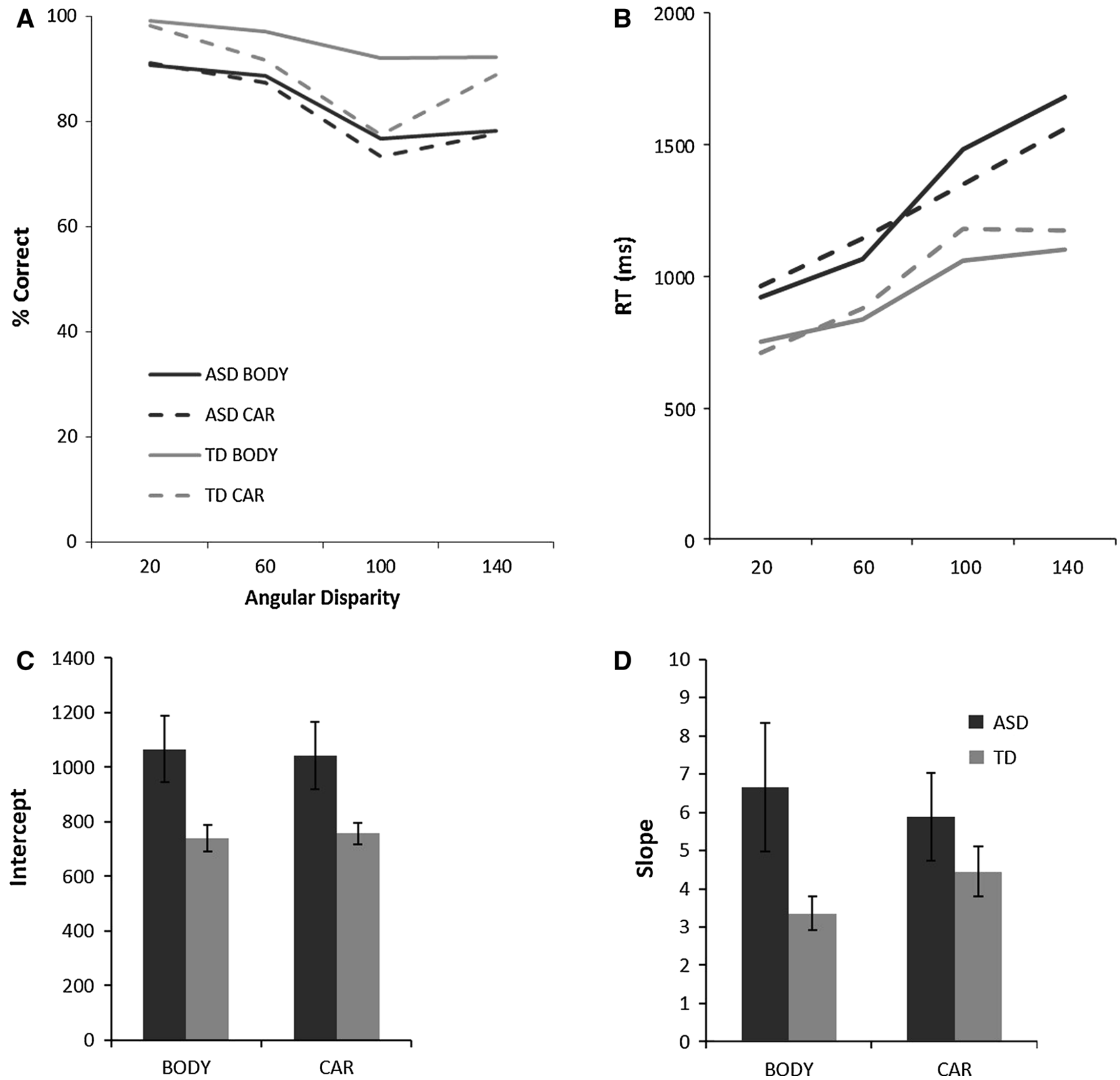

Fig. 3 In all plots the *black lines/columns* represent the ASD group and the *grey lines/columns* represent the TD group. In the upper plots the *solid lines* display performance on the body stimuli and the *dashed lines* display performance for the car. **a** Displays the effects of angular disparity on accuracy. **b** Displays effect of Orientation on RT in the egocentric task for ASD and TD groups' performance on the body and car. **c** Displays effects of group and form on intercepts, and **d** displays effects of group and form on slope

decreased. There was a marginal interaction between form and angular disparity [F(2.05, 69.81) = 2.98, $p = 0.056$, $\eta^2 = 0.081$] showing that as angular disparity increased accuracy for the car decreased, but stayed relatively stable for the body. All other two and three interactions were non-significant.

A repeated measures ANOVA examining median response times (see Table 3) in the egocentric task revealed that there was a significant effect of group [F(1, 33) = 12.55, $p = 0.001$, $\eta^2 = 0.275$] showing overall that the ASD group had slower RT's than the typical group (Fig. 3a, the ASD group are represented by the black lines). There was no significant effect of form however there was a significant effect of angular disparity [F(1.470, 48.51) = 47.46, $p < 0.001$, $\eta^2 = 0.590$] with RT's increasing as angular disparity between the participant and the stimulus increased. There was an interaction between angular disparity and group [F(3, 99) = 3.56, $p = 0.049$, $\eta^2 = 0.098$] with the ASD group more strongly affected by angular disparity than the typical group. There were no further interactions between group, form and angular disparity.

We also note that the variance in the ASD group was higher than in the TD group for median response times across tasks (Tables 2 and 3). Levene's tests for equality of variance showed group differences ($p < 0.05$) for the egocentric body-20°, car-100° and car-140° stimuli, and for the mental rotation car-40°, car-80° and car-160° stimuli.

Table 2 Median response times in the mental rotation task ± SD

Angular disparity	40	80	120	160
ASD BODY	1,796 ± 639	2,312 ± 975	2,314 ± 983	2,430 ± 1,062
ASD CAR	2,053 ± 1,116	2,144 ± 1,036	2,142 ± 1,285	2,183 ± 1,146
TD BODY	1,653 ± 824	1,907 ± 771	1,820 ± 823	1,949 ± 766
TD CAR	1,529 ± 393	1,763 ± 588	1,567 ± 503	1,425 ± 453

Table 3 Median response times in the egocentric task ± SD

Angular disparity	20	40	100	140
ASD BODY	922 ± 808	1,064 ± 489	1,480 ± 388	1,683 ± 357
ASD CAR	960 ± 644	1,141 ± 478	1,350 ± 466	1,562 ± 449
TD BODY	749 ± 353	835 ± 357	1,066 ± 227	1,098 ± 181
TD CAR	708 ± 376	876 ± 382	1,181 ± 157	1,172 ± 126

Several other studies have noted higher variability in participants with autism compared to TD participants (Dakin and Frith 2005; Simmons et al. 2009). It is possible that participants with autism found some stimuli more difficult at certain angular disparities. However due to a lack of an interaction between group, angular disparity and form in both the mental rotation and egocentric tasks, exploring this possibility in detail is beyond the scope of the present paper (Table 4).

Slopes and intercepts in the egocentric task were each examined using a repeated measures ANOVA with group entered as a between subjects factor (Fig. 3c, d, the ASD group are represented by the black columns). The effect of group on regression slope was marginally significant [$F(1, 34) = 2.90$, $p = 0.097$, $\eta^2 = 0.079$] with the ASD group showing marginally more positive slopes than the typical group. This is also reflected in the response time data in the interaction between group and angular disparity. Effect of form and interactions between form and group were not significant. For intercepts there was a significant effect of group [$F(1, 34) = 5.33$, $p = 0.03$, $\eta^2 = 0.136$] with the typical group showing significantly lower intercepts than the ASD group. These results are reflected in the significant effect of group on RT. There was no significant effect of form and no interaction between form and group.

Comparison Across Tasks

In order to examine whether there were any differences in spatial ability and perceptual processing overall between egocentric transformations and mental rotation we compared slopes and intercepts across tasks. This was done by performing a repeated measures ANOVA on both slope and intercept with group as a between subjects factor and within subjects factors of task and form.

Table 4 Summary of main results found in the mental rotation task and egocentric task with *p* values and effect size

	Mental rotation		Egocentric	
	p	η^2	*p*	η^2
Accuracy				
Group	0.104	0.076	0.038	0.12
Form	0.66	0.006	0.478	0.015
Angular disparity	0.001	0.147	0.001	0.412
Angular disparity*form	0.014	0.099	0.056	0.081
Response time				
Group	0.054	0.105	0.001	0.275
Form	0.257	0.038	0.878	0.001
Angular disparity	0.001	0.105	0.001	0.59
Angular disparity*form	0.001	0.182	0.001	0.182
Group* angular disparity	0.03	0.083	0.049	0.098
Slope				
Form	0.001	0.309	0.097	0.079
Group	0.289	0.033	0.686	0.005
Intercept				
Form	0.686	0.005	0.670	0.005
Group	0.067	0.095	0.03	0.136

For slopes there was a significant effect of task [$F(1, 34) = 23.61$, $p < 0.001$, $\eta^2 = 0.410$] with steeper slopes in the egocentric task and a significant effect of group [$F(1, 34) = 4.13$, $p = 0.05$, $\eta^2 = 0.108$] with the ASD group showing steeper slopes than the typical group. There was a marginal effect of form [$F(1, 34) = 3.05$, $p = 0.09$, $\eta^2 = 0.082$] and a significant task by form interaction [$F(1, 34) = 8.65$, $p = 0.006$, $\eta^2 = 0.203$] with similar slopes between bodies and cars in the egocentric task but higher slopes for bodies compared to cars in the mental rotation task. All other interactions were non-significant.

For intercepts there was a significant effect of task [$F(1, 34) = 107.6$, $p < 0.001$, $\eta^2 = 0.760$] with lower intercepts in the egocentric task and a significant effect of group [$F(1, 34) = 5.99$, $p = 0.02$, $\eta^2 = 0.150$] with the typical group showing lower intercepts than the ASD group. There was no significant effect of form, and no further interactions.

Discussion

The current study aimed to investigate whether people with autism are able to perform different types of spatial transformation and how difficulties in these abilities may contribute towards impaired perspective taking in this population. Results of the mental rotation task showed that people with autism were as accurate as typical participants and only marginally slower in the non-rotational aspects of the task. Results from the egocentric task showed that people with autism were significantly less accurate and slower with a particular difference in the non-rotational aspects of the task. Here we discuss each individual task and then consider the results across tasks to establish how these data can help us understand spatial transformations in autism.

Mental Rotation Task

Participants with autism were as accurate as typical participants in this task and showed no difference in the slope parameter which indexes mental rotation itself. However, a marginal group difference was present in the intercept parameter which indexes the non-rotational aspects of the task. These include perceptual processing, decision making and implementation of a response.

These results can be compared with previous research on mental rotation in autism, which found differences in intercept but not slope in ASD and typical participants (Falter et al. 2008). Falter's study found that children with autism had lower intercepts than typical children but had similar slopes. Both studies agree that individuals with autism show similar slope parameters to typical individuals, suggesting that the core mental rotation component of this task is intact in autism. However, the studies differ in the results for the intercept parameter which relates to non-rotational components of the task. Falter's ASD participants had lower intercepts (faster processing) than typical participants, while our ASD participants had higher intercepts (slower processing) than typical participants. Falter et al interpreted their data to suggest that the children with ASD were using a local feature based processing strategy, attributed to weak central coherence. It is possible that our participants chose instead to use a configural strategy even if this resulted in slower reaction times. This would be coherent with data from Behrmann et al. (2006) who found that people with autism were able to use a configural processing strategy in a face recognition task, but it slowed response times as a result.

A key difference between our study and Falter's is the stimuli used. In the current study a body and a car were used as stimuli whereas as Falter's (2008) study used meaningless geometric shapes. It is possible that familiar stimuli prompt the participants with autism to use a configural strategy (even when it is slower) while for novel stimuli they use a feature-based strategy. It has been shown that participants are more likely to use a configural processing strategy for familiar stimuli (Behrmann et al. 2006; Logothetis and Sheinberg 1996). Interestingly, data from typical individuals in the body processing literature has shown that the areas involved in configural processing also show selective responding to familiar stimuli (Hodzic et al. 2009). These findings all support the claim that participants in the current study used a more configural as opposed to a feature based method of processing. It is clear that more research is needed into differences between configural and feature-based processing in autism, using stimuli beyond faces (Behrmann et al. 2006) or bodies (Hodzic et al. 2009).This would provide a deeper understanding of what drives people with autism to use different processing strategies for different types of stimuli.

There was also a surprising effect of form on performance of both typical and autistic participants in the mental rotation task. We expected that all participants would show a positive slope (increase in response time with increased angular disparity) for both the car and body stimuli, replicating previous findings for stimuli such as letters, limbs, and meaningless geometric shapes (Kosslyn et al. 1998; Parsons 1987; Shepard and Metzler 1971). In fact, for the car stimuli the slope parameter for the ASD group was around zero and the typical group displayed a negative slope. As participants did not show a positive slope for the car stimuli, this suggests that they did not use a spatial rotation strategy to determine if these stimuli were the same. The reasons for this are not clear, but we speculate that is might relate to the familiarity and manipulability of the car.

Cars are familiar everyday objects that are often viewed from different orientations but rarely turned in the hand (except in toy form). Studies suggest that presenting familiar items encourage a configural mental rotation strategy (Logothetis and Sheinberg 1996). Using familiar everyday objects that we see often from different viewpoints (such as mobile phones and radios), researchers have demonstrated the expected mental rotation effect. (Yu and Zacks 2010; Zacks and Tversky 2005). However, these items are small and highly manipulable items compared to a car. It has been suggested that motor processes contribute to mental rotation skills (Wexler et al. 1998). If this is true, it may be easier to mentally rotate a mobile phone than a car. It would be interesting to test this directly in the future, and to determine if experience with handling toy cars influences performance. Future research into mental rotation using a variety of everyday objects and different planes of rotation would be useful in providing clarity on these findings.

Egocentric Transformations Task

In the egocentric task, the participants with autism were both slower ($\eta^2 = 0.275$) and less accurate ($\eta^2 = 0.120$) than the typical participants. The effect sizes here are moderate, and larger than the equivalent effect sizes for the mental rotation task. This effect of group was also apparent in both the slope and intercept parameters, suggesting that both the rotational and non-rotational aspects of the task were harder for participants with autism. There are two possible explanations for poor performance on the egocentric task in the participants with autism. They might have difficulties with laterality judgements or difficulties relating self and other (Rogers and Pennington 1991). We discuss each in turn.

It is possible that people with ASD may have problems with laterality judgements and distinguishing their left from right. However, studies which have used laterality judgements in autism have not necessarily found group differences (David et al. 2010). Previous studies into handedness in ASD have shown that many people with ASD are ambidextrous and may show an ambiguous handedness profile switching arbitrarily between left and right (Cornish and McManus 1996; Soper et al. 1986). This could make it more difficult for them to make judgements about laterality due to confusion between left and right. Handedness was not equated across groups, seventeen out of the eighteen TD participants were right handed and fourteen out of the eighteen ASD participants were right handed. Two of the ASD participants were left handed and two of the ASD participants reported ambidextrous handedness. We also did not collect any data on handedness aside from self-reported hand dominance so we cannot rule out general problems with laterality having an effect on performance. In future this may be worth taking into consideration when using laterality tasks with ASD participants.

Another possibility is that people with autism have a general difficulty with making judgements involving the self, or involving the relationship between self and other. Previous studies have shown that people with autism struggle when making self-referential judgements (Frith and de Vignemont 2005; Lombardo et al. 2010), which has been related to an inability to properly distinguish between the self and others. The ability to perform the egocentric task required the participant to use the self as a reference point for performing a spatial transformation. Thus impairments in making self/other distinctions would impact on the ability to perform the task. Our results also support the data from Kessler and Wang (2012) who found that autistic traits within the general population are related to performance on an egocentric transformation task, with a weaker tendency to use an egocentric strategy among those with high levels of autistic traits. In a similar task Brunye et al. (2012) found that participants with high levels of autistic traits were able to use an embodied egocentric transformation, but that they were significantly slower than low autistic trait participants.

Difficulties with self-referential processing also provide a possible link between the egocentric transformation task used here and visual perspective taking tasks studied previously (Hamilton et al. 2009). Yu and Zacks (2010) and Surtees et al. (2013) have suggested that egocentric transformations are the underlying step used to put ourselves in someone else's place in order to see things from their point of view. If data on visual perspective taking or other social-cognitive measures were available for the present participants, it would be possible to test this fully. Unfortunately, such data was not collected in these participants and so links between egocentric transformations, VPT and other socio-cognitive abilities in autism must wait for the future. At present, our results suggest that a specific difficulty with egocentric transformations could be one explanation for poorer performance in visual perspective taking, but these results demand further exploration.

Comparisons Across Tasks

When we directly compared slope and intercept parameters across tasks, participants with autism showed steeper slopes (worse at rotation) and higher intercepts (worse at non-rotational components) with no interactions between task and group. This means that our interpretation of the reasons for the performance decrements in the mental rotation and egocentric tasks above must be tempered—it is possible that a single, global slowing of performance accounts for differences in both tasks. Such a global process might involve perception, rotation in space, and decision making.

This is congruent with the finding that the intercept parameter showed group differences in our task. The intercept parameter indexes the non-rotational aspects of the task such as perception and decision making. If these things are harder for participants with autism, then this global difference could account for some of the effects we report here. It is worth noting that our participant groups were matched on age and IQ, so basic cognitive ability should be similar between groups. None of our participants had an intellectual disability and it was not feasible to collect data from participants of lower cognitive ability on this relatively demanding task. Previous research has shown that people with autism generally tend to exhibit slower response times than TD people on perceptual tasks (Calhoun and Mayes 2005). Thus, differences in perceptual processing might impact on task performance.

The lack of a group by task interaction in our data makes it hard to draw strong conclusions about differences between mental rotation and egocentric transformations in autism. A negative result of this form could reflect a lack of power in the analysis, and does not mean that mental rotation and egocentric transformations are both impacted in the same way in autism. Thus, it remains possible that the participants in this study are overall slower in perceptual processing but also have a specific difficulty with egocentric transformations. Further study will be required to test this.

Conclusions

The results from this study provide a contribution to our understanding of spatial processing in autism. The use of a carefully controlled design allowed us to closely examine the effects that using different spatial tasks and stimuli can have on performance of spatial transformations in both autistic and typical participants. The results suggest that overall participants with autism found the non-rotational aspects of the task difficult and there may also be subtle difficulties with using the self as a reference frame. Such difficulties could impact on the ability to see things from another point of view and may go some way to explaining perspective taking difficulties in autism.

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