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The effects of grouping on speed discrimination thresholds in adults, typically developing children, and children with autism

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Adult observers show elevated speed discrimination thresholds when comparing the speeds of objects moving across a boundary compared to those moving parallel to a boundary (Verghese & McKee, 2006)—an effect that has been attributed to grouping processes in conjunction with a prior for smooth motion. Here, we extended Verghese and McKee's (2006) paradigm to typically developing children ($n = 35$) and children with autism ($n = 26$) and compared their performance with that of typical adults ($n = 19$). Speed discrimination thresholds were measured in three conditions: (a) with dots moving parallel to a boundary, (b) with dots moving perpendicular to a boundary, and (c) with dots in each stimulus half moving in orthogonal, oblique directions. As expected, participants had higher speed discrimination thresholds when dots appeared to cross a boundary compared to when dots moved parallel to the boundary. However, participants had even higher thresholds when dots moved in oblique, orthogonal directions, where grouping should be minimal. All groups of participants showed a similar pattern of performance across conditions although children had higher thresholds than adult participants overall. We consider various explanations for the pattern of performance obtained, including enhanced sensitivity for shearing motions and reduced sensitivity for discriminating different directions. Our results demonstrate that the speed discrimination judgments of typically developing children and children with autism are similarly affected by spatial configuration as those of typical adults and provide further evidence that speed discrimination is unimpaired in children with autism.

Introduction

Motion processing is an important aspect of visual functioning, helping observers to follow trajectories, segment scenes, perceive depth, and recognize objects. Like other aspects of visual perception, motion processing is considerably influenced by information presented in the past (Seriès & Seitz, 2013; Summerfield & de Lange, 2014). Statistical regularities are exploited to form expectations (or "priors"), which guide and bias the perception of dynamic stimuli. For example, when an object's motion is ambiguous (e.g., if the object is viewed under low contrast conditions), it is

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often perceived to move more slowly than its actual speed, reflecting a prior assumption that most objects are either stationary or slow moving (Weiss, Simoncelli, & Adelson, 2002). Similarly, an object's trajectory leads to expectations about its velocity based on previous natural events, biasing perception (La Scaleia, Zago, Moscatelli, Lacquaniti, & Viviani, 2014).

Verghese and McKee (2006) reported that adults are less sensitive to speed differences when discriminating sets of random dots that appear to cross a boundary compared to sets of dots that move parallel with a boundary. The authors argued that this result reflected accumulated knowledge that objects tend to change speed smoothly rather than abruptly. Objects that cross a boundary are grouped together by virtue of their common motion, and observers lose access to the local speed differences on either side of the boundary as a result of their prior for smooth motion. In a set of various control conditions, Verghese and McKee demonstrated that speed discrimination sensitivity could be improved if grouping was broken, for example, by placing a gap between the two sets of dots to be discriminated or by having the two sets of dots move in different directions.

This study investigated whether typically developing children and children with autism would be equally susceptible to the grouping influences proposed by Verghese and McKee (2006). Previous research has established that speed discrimination sensitivity develops slowly in typical development, reaching adult-like levels only by mid-to-late childhood (Manning, Aagten-Murphy, & Pellicano, 2012). There may also be age-related changes in the effects of grouping on speed discrimination. Although children make use of prior information from an early age (Sciutti, Burr, Saracco, Sandini, & Gori, 2014; Thomas, Nardini, & Mareschal, 2010), the weighting assigned to these priors may change as the child develops (Stone, 2011; Thomas et al., 2010). Furthermore, it has been suggested that the extent of global processing increases with age (Dukette & Stiles, 1996; Harrison & Stiles, 2009; Kramer, Ellenberg, Leonard, & Share, 1996; Poirel, Mellet, Houdé, & Pineau, 2008; Tada & Stiles, 1996; Vinter, Puspitawati, & Witt, 2010; but see also Enns & Girgus, 1985). An increased tendency toward local processing in younger children may mean that they are less affected by grouping when perceiving motion.

There are also reasons to expect that children with autism may be differentially affected by grouping compared to typically developing children. Although autism is most well known for its effects on social communication and interaction, it also affects how individuals perceive the world around them with many autistic individuals experiencing sensory symptoms (American Psychiatric Association, 2013). Reduced sensitivity to motion information has been reported in children with autism for some tasks that appear to require grouping (e.g., coherent motion perception, Milne et al., 2002; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Spencer et al., 2000; biological motion perception, Annaz et al., 2010; Blake, Turner, Smoski, Pozdol, & Stone, 2003; see Simmons et al., 2009, for review). In contrast, children with autism appear to be equally sensitive to speed information as typically developing individuals (Manning, Charman, & Pellicano, 2013).

Children with autism may perform differently from typically developing children in Verghese and McKee's (2006) motion grouping paradigm for two reasons. First, prominent cognitive theories of autism suggest that children with autism may not group motion information to the same extent as typically developing children. The weak central coherence account (Frith & Happé, 1994; Happé & Booth, 2008) suggests that grouping processes may be weakened in individuals with autism because they have a tendency to process local stimulus features at the expense of the global "whole." Related accounts argue that global processing is not weakened in autism but that local processing is enhanced (Mottron et al., 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Plaisted, 2000, 2001). In support of these theories, individuals with autism display an increased tendency to attend to the local level when freely viewing hierarchical figures (Koldewyn, Jiang, Weigelt, & Kanwisher, 2013; Plaisted, Swettenham, & Rees, 1999), enhanced performance in the Embedded Figures Test (Shah & Frith, 1983), superior performance in visual search tasks (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001), reduced use of Gestalt grouping principles (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Brosnan, Scott, Fox, & Pye, 2004; Farran & Brosnan, 2011, but see also Hadad & Ziv, 2014), and reduced susceptibility to grouping effects in multiple object tracking tasks (Evers et al., 2014, but see also O'Hearn, Franconeri, Wright, Minshew, & Luna, 2013). An increased tendency for autistic individuals to perceive local information instead of the global percept may thus lead to reduced grouping between parts of the stimulus.

Second, individuals with autism may not make effective use of accumulated knowledge that objects crossing a boundary belong to a common motion path with a similar speed. Pellicano and Burr (2012) proposed that individuals with autism rely less on prior information than typical individuals as a result of having attenuated priors. According to this account, individuals with autism may have a weaker prior assumption that objects crossing a boundary share the same speed. Therefore, children with autism may be less affected by the grouping conditions in Verghese and McKee's (2006) paradigm without necessitating a grouping deficit per se.

In the current study, we asked typical adults, typically developing children, and children with autism to discriminate the speed of two sets of dots that (a) appeared to cross a boundary, (b) moved parallel with a boundary, and (c) moved in different directions. This manipulation allowed us to address whether the speed discrimination thresholds of children with and without autism are affected by motion grouping in a similar way to those of typical adults (cf. Verghese & McKee, 2006).

Based on previous research (Ahmed, Lewis, Ellemberg, & Maurer, 2005; Manning et al., 2012; Manning et al., 2013), we hypothesized that typically developing children and children with autism would have higher speed discrimination thresholds than adults overall and that the performance of children with autism would be comparable to that of typically developing children. Importantly, however, we hypothesized that typically developing children would demonstrate reduced sensitivity to grouping compared to adults and that children with autism would be even less susceptible to grouping influences than typically developing children.

Methods

Participants

Three groups of participants were tested: adults with no reported past or current developmental conditions ($n = 19$, 13 females; age: $M = 26$ years, 0 months, $SD =$ 3, 8, range: 20, 6–32, 11), typically developing children with no diagnosed developmental conditions as reported by parents ($n = 35$), and children with an independent clinical diagnosis of an autism spectrum condition ($n = 26$). The groups of typically developing children and children with autism were matched in terms of age, $t(59) = 1.40$, $p = 0.17$; nonverbal ability, $t(59) = 0.18$, $p = 0.86$; and full-scale ability, $t(59) = 1.24$, $p = 0.22$, as assessed by the Wechsler Abbreviated Scales of Intelligence (WASI or WASI-II; Wechsler, 1999, 2011; see Table 1 for scores). The children with autism had lower verbal IQ scores than the typically developing children, $t(59) = 2.41$, $p = 0.02$, consistent with their clinical profile. Parents of typically developing children and children with autism completed the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003), and children with autism were administered the Autism Diagnostic Observation Schedule (ADOS-G or ADOS-2; Lord, Rutter, DiLavore, & Risi, 1999; Lord et al., 2012) using the revised algorithm (Gotham et al., 2008; Gotham, Risi, Pickles, & Lord, 2007). Children with autism were included in the study if they scored above threshold for an autism spectrum condition on one or both of these measures (Manning et al., 2013). Two additional children with autism were excluded from the data set for not meeting the autism spectrum cutoff on either diagnostic measure. All typically developing children scored below the cutoff for autism on the SCQ (<15; Rutter et al., 2003; see Table 1 for scores of participants included in the final data set). As expected, the children with autism had higher SCQ scores than the typically developing children, $t(21.98) = 11.06$, $p < 0.01$.

Characteristic	Typically developing children	Children with autism
n	35	26
Gender (*n* males:*n* females)	20:15	20:6
Age (years, months)		
Mean (*SD*)	9, 11 (2, 1)	10, 8 (2, 1)
Range	6, 8–13, 6	6, 7–14, 3
Performance IQ		
Mean (*SD*)	104.06 (12.19)	104.65 (13.66)
Range	80–128	75–137
Verbal IQ		
Mean (*SD*)	108.09 (7.88)	101.73 (12.66)
Range	95–128	73–130
Full-scale IQ		
Mean (*SD*)	107.00 (8.77)	103.65 (12.38)
Range	89–128	80–129
SCQ score		
Mean (*SD*)	4.07 (3.46)	23.12 (8.15)
Range	0–14	5–35
ADOS total score		
Mean (*SD*)		11.46 (5.22)
Range		4–22

Table 1. Group characteristics of typically developing children and children with autism included in the data set. *Notes*: SCQ = Social Communication Questionnaire (Rutter et al., 2003). ADOS = Autism Diagnostic Observation Schedule (Lord et al., 1999; Lord et al., 2012). IQ scores were assessed using the Wechsler Abbreviated Scales of Intelligence (WASI or WASI-II; Wechsler, 1999, 2011).

The study was conducted in accordance with the principles of the Declaration of Helsinki, and the procedure was approved by the UCL Institute of Education's Faculty Research Ethics Committee. Parents gave written informed consent for their children's participation in the study, and children provided their verbal assent.

An additional three children with autism and two typically developing children were excluded from analysis because they did not meet a criterion of four consecutive correct responses in the practice phase in one or more conditions (see Procedure). A further four children with autism, five typically developing children, and three adults were excluded from the data set for not

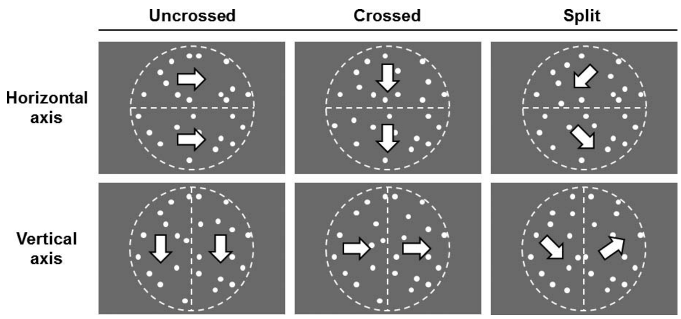

Figure 1. Schematic representation of stimuli presented in different task conditions. Participants were randomly assigned to the horizontal axis (upper panel) or vertical axis (lower panel) conditions. The dots in one half of the stimulus moved at a reference speed (6°/s), and the dots in the other half moved at a comparison speed. Arrows indicate the direction of movement of dots in each half of the stimulus. Note that the outline of the aperture and dividing line (dashed lines) are presented for illustrative purposes here and were not visible in the experiment.

performing significantly above chance in the catch trials in one or more conditions (see Procedure).

Apparatus and stimuli

Stimuli were presented on a Dell Precision laptop (1366 × 768 pixels, 60 Hz) using MATLAB and elements of the Psychophysics Toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). The screen was gray with a white central fixation dot (diameter 0.43°) presented before stimulus presentation. Stimuli were composed of two sets of randomly placed dots moving behind a central aperture (diameter 12°) for 300 ms. The two sets of dots were presented on either side of an invisible boundary that divided the circular aperture (see Figure 1) with dots on one side of the boundary moving at a reference speed of 6°/s and the dots on the other side moving at a comparison speed above the reference speed. There were 200 white dots on each side of the stimulus, each measuring 0.23° in diameter. Dots moved with unlimited lifetime with those moving outside of their respective stimulus half being wrapped around to the other side in order to maintain a constant density of 2.80 dots/$^{\circ 2}$ in each stimulus half.

Procedure

Participants completed a speed discrimination task in three stimulus conditions that were based on an informative selection of conditions presented by Verghese and McKee (2006; see Figure 1). In the *crossed* condition, the two sets of dots to be discriminated moved in a direction that was consistent with them appearing to cross the boundary. The dots did not actually cross the boundary as changes in speed at the boundary would lead to changes in dot density (note that it is not clear whether the dots crossed the boundary in the corresponding condition presented by Verghese & McKee). In the *uncrossed* condition, the two sets of dots moved in a direction parallel with the boundary. Increased sensitivity in the uncrossed condition compared to the crossed condition could reflect shearing cues in the uncrossed condition. Therefore, participants also completed a *split* condition in which the two sets of dots moved in orthogonal, oblique directions. In this condition, grouping is broken and shearing is minimized.

To ensure that differences in sensitivity in the uncrossed and crossed conditions were not due to differences in sensitivity to horizontal and vertical motion, the participants were randomly assigned to vertical and horizontal dividing axis conditions (see Figure 1). The direction of motion was randomized in each trial. In the horizontal-uncrossed and vertical-crossed conditions, the direction was randomly set to either leftward (−90°) or rightward (+90°) motion. In the horizontal-crossed and vertical-uncrossed conditions, the direction was randomly set to either upward (0°) or downward (180°) motion. In the split conditions, the direction was randomized between downward and upward oblique, orthogonal motions. Thus, in the horizontal axis condition, the motion was randomly set to −135° in the top half and +135° in the bottom half of the stimulus (as depicted in Figure 1) or +45° in the top half and −45° in the bottom half. In the vertical axis condition, the motion was randomly set to +135° in the left half and +45° in the right half (as depicted in Figure 1), or −45° in the left half and −135° in the right half.

The task was presented in the context of a child-friendly game whereby participants were asked to judge which of two flocks of migrating "birds" moved fastest. To aid motivation, participants were told that they were competing against a cartoon character, "Bernard the Birdwatcher." A central fixation point was presented at the beginning of a trial. The experimenter initiated the trials for children when they were attending to the screen whereas adults initiated the trials for themselves. Participants were asked to judge which half of the stimulus had dots that were moving faster and to press the corresponding response key on a number pad.

Introduction and practice phase

Each task condition began with an introductory phase in which the experimenter explained the task to participants using images and animations. Eight practice trials were then presented in order of increasing difficulty with comparison speeds of 20°/s, 15°/s, 12°/s, 10°/s, 9°/s, 8°/s, 7°/s, and 6.5°/s. The half of the stimulus in which the reference speed appeared (top/bottom in the horizontal axis condition and left/right in the vertical axis condition) was randomized across trials. Next, up to 20 criterion trials were presented with a comparison speed of 12°/s. Participants who failed to reach a criterion of four consecutive responses within 20 trials were given a short version of the task and removed from the data set ($n = 5$, see Participants). Participants who met the criterion proceeded to the threshold estimation phase of the experiment. Visual and verbal feedback was provided after each trial throughout the practice phase.

Threshold estimation phase

In the threshold estimation phase, the comparison speed was determined by QUEST (Watson & Pelli, 1983). In each condition, two staircases of 32 trials ran interleaved. In one staircase, the reference speed was presented in a certain stimulus half (e.g., top in the horizontal axis condition or left in the vertical axis condition), and in the other staircase, it was presented in the opposite location. Sixteen additional catch trials were randomly interleaved using the comparison speed presented in the criterion phase (12°/s), yielding a total of 80 trials per condition. Each QUEST staircase had a beta value of 3.5 and a lapse rate set to 0.02. As recommended by Watson and Pelli (1983), a random "jitter" was added to values suggested by QUEST of up to ± 0.2°/s.

No feedback regarding accuracy was provided in this phase although general encouragement was provided throughout. A short break was given after a block of 20 trials in which the participant was shown a simulated graph of the "points" he or she and "Bernard the Birdwatcher" had attained. These points were randomly jittered around a fixed set of values to minimize reward and motivation effects on threshold estimates (see Manning, Dakin, Tibber, & Pellicano, 2014).

General procedure

The experimental conditions were presented in a session lasting approximately 15 min. The three conditions could be presented in six possible order permutations. Participants were randomly allocated to one of these six permutations so that the order of conditions was counterbalanced among participants. Participants were seated in a dimly illuminated room at a distance of 50 cm from the screen. The WASI and the ADOS were administered to children in further sessions.

Data screening and analysis

The proportion of incorrect responses to catch trials was calculated for each participant in each task condition. The proportion of incorrect responses to catch trials was used to estimate lapse rate (Manning et al., 2013; Treutwein, 1995). Data for each participant in each condition were bootstrapped (Efron & Tibshirani, 1993) and fit with a cumulative Gaussian function, using the "maximum likelihood" fitting method (Watson, 1979) and assuming the lapse rate estimated from the catch trials (see Manning et al., 2013, for further details). The 75% correct threshold was converted to Weber fractions for analysis using the following formula: Weber Fraction = (raw threshold − reference speed)/reference speed.

Finally, the data were screened for potential outliers. Z scores were calculated using the mean Weber fraction values and standard deviations for each group in each condition, and outliers were defined as data points with z scores of absolute values above three. One outlier was identified belonging to a typically developing child in the split condition ($z > 3$) that was replaced with a value corresponding to a z score of 2.5 (Tabachnick & Fidell, 2007). All reported analyses were conducted on the sample following exclusions of participants who failed to pass the criterion in the practice phase and those who did not perform significantly above chance in the catch trials (see Participants section).

Results

Following Verghese and McKee (2006), we hypothesized that participants would have higher Weber fractions in the crossed condition than in the uncrossed and split conditions. Also, we predicted that children both with and without autism would have higher Weber fractions than adults but that children with autism would show comparable Weber fractions to typically developing children overall (cf. Manning et al., 2013). Critically, we predicted an interaction between condition and group, whereby children, particularly children with autism, would show a reduced effect of grouping. In this task, reduced grouping should manifest as a smaller reduction in sensitivity in the crossed condition compared to the uncrossed and split conditions.

Preliminary analyses revealed that axis (vertical, horizontal) had no significant effect on Weber fractions, $F(1, 74) = 1.86$, $p = 0.18$, and no interactions with condition or group, $p\text{s} \geq 0.14$. There was neither an effect of gender, $F(1, 74) = 0.37$, $p = 0.55$, nor interactions involving gender, $p\text{s} \geq 0.41$. These factors were therefore removed from further analysis.

Mean Weber fractions collapsed across axis condition are displayed in Figure 2. A mixed-design ANOVA with condition as a within-participant factor and group (adults, typically developing children, children with autism) as a between-participants factor revealed a significant main effect of condition, $F(2, 154) = 20.22$, $p < 0.001$, $\eta_p^2 = 0.21$. As expected, planned contrasts revealed significantly lower Weber fractions in the uncrossed condition than the crossed condition, $F(1, 77) = 20.25$, $p < 0.001$, $\eta_p^2 = 0.21$. Unexpectedly, however, Weber fractions in the split condition were significantly higher than those in the crossed condition, $F(1, 77) = 4.73$, $p = 0.03$, $\eta_p^2 = 0.06$.

There was also a significant main effect of group, $F(2, 77) = 5.33$, $p = 0.01$, $\eta_p^2 = 0.12$. Planned contrasts showed that adults had significantly lower Weber fractions than the child groups, $t = 3.16$, $p = 0.002$, but that the children with autism performed similarly to the typically developing children, $t = 0.15$, $p = 0.88$. In contrast to predictions, there was no significant interaction between condition and group, $F(4, 154) = 0.42$, $p = 0.80$, indicating that all groups of participants were similarly affected by the task conditions.

To ensure that the results were not confounded by differences in verbal ability between children with and without autism (see Participants section), we conducted an ANCOVA on children's speed discrimination thresholds with verbal IQ as a covariate. As in the main analysis, we found no difference in performance between children with autism and typically developing children, $F(1, 58) = 0.04$, $p = 0.83$, and no interaction between condition and group, $F(2, 116) = 0.24$, $p = 0.79$. Finally, we investigated whether speed discrimination thresholds were related to autism symptomatology. No relationships were found between speed discrimination thresholds and scores on either the SCQ or ADOS ($ps \geq 0.26$).

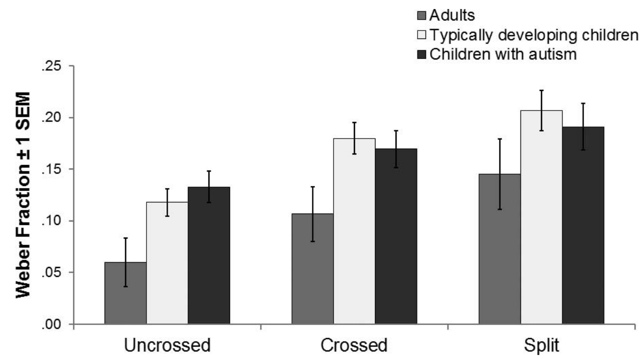

Figure 2. Mean Weber fractions for adults, typically developing children, and children with autism by condition. Error bars represent ±1 *SEM*.

Discussion

This study aimed to investigate the effects of grouping on the speed discrimination thresholds of adults, typically developing children, and children with autism based on a previous report that motion grouping impairs speed discrimination in adult observers (Verghese & McKee, 2006). Participants completed a speed discrimination task under three conditions, one of which was designed to elicit grouping between the two halves of the stimulus (crossed condition) and the other two that were designed to minimize grouping between the two halves of the stimulus (uncrossed and split conditions). Consistent with Verghese and McKee's (2006) results, participants performed more poorly when dots appeared to cross a boundary (crossed condition) than when dots moved parallel to a boundary (uncrossed condition). In Verghese and McKee's study, adult observers had low thresholds in the split condition, in which dots moved in oblique, orthogonal directions. In contrast, participants in the current study demonstrated elevated thresholds in this condition, obtaining thresholds higher than those found in the crossed condition. Furthermore, all groups of participants showed a similar pattern of performance across the experimental conditions although children had higher thresholds than adult participants overall.

What might be driving the discrepancy between our findings and those reported by Verghese and McKee (2006)? There are at least two possibilities. First, compared to the present study, Verghese and McKee presented stimuli with a shorter duration (200 ms) and a faster reference speed (12°/s). We increased the presentation time to reduce the attentional demands for children and reduced the reference speed to be in line with previous studies of speed discrimination in childhood (e.g., Manning et al., 2012; Manning et al., 2013). Yet, although the duration and speed of stimuli are known to affect Weber fractions (e.g., de Bruyn & Orban, 1988; Snowden & Braddick, 1991), we know of no reason to suggest that these should have a differential effect on the conditions presented.

Second, another difference between the current study and that of Verghese and McKee (2006) concerns the participants tested. Verghese and McKee focused on characterizing the performance of a small number of observers (including two authors and two naïve participants) over an extensive range of stimulus conditions whereas in our group-based study, we sacrificed some of these conditions to make the task appropriate for children with and without autism. It is possible that considerable individual differences in performance in these task conditions may be obscured when testing a few observers. Furthermore, Verghese and McKee showed that the extent of differences between conditions could be changed with practice on the task, leading to the possibility that individuals with little or no previous exposure to psychophysical testing (as tested here) perform differently from those who have more experience with psychophysical experiments (as in Verghese & McKee). Verghese and McKee also provided participants with trial-by-trial feedback, which may have made practice effects even more pronounced in their study. The discrepancy between the current results and those of Verghese and McKee suggest, more generally, that results obtained from a small number of highly practiced observers may not be informative about how members of the general population see things in everyday life. Although these psychophysical studies clearly have value in establishing the limits of visual sensitivity, it would be worthwhile for future studies to replicate the results with larger groups of naïve observers.

We now consider possible explanations for the pattern of results obtained within the current study. First, it is possible that participants had high thresholds in the split condition because the motion in the two stimulus halves was, in fact, grouped by participants as in the crossed condition. Indeed, participants may have perceived continuous motion that appeared to "turn a corner" in the split condition. We know of no research that has systematically investigated the angular separation required to invoke segmentation at a boundary. However, studies investigating motion transparency suggest that grouping occurs for superimposed dot patterns differing by less than ~45° (Braddick, Wishart, & Curran, 2002; Edwards & Nishida, 1999; Greenwood & Edwards, 2007; Smith, Curran, & Braddick, 1999) with the range for grouping two spatially distinct populations of dots being even smaller (Smith et al., 1999). To investigate this phenomenon further, future studies could present a variant of the split condition in which the orthogonal, oblique directions could not feasibly appear to cross the boundary (for example, with directions of −45° and +45° on either side of a vertical boundary).

Second, it could be suggested that participants have reduced sensitivity to oblique directions compared to cardinal directions, explaining why participants perform more poorly in the split condition than the uncrossed condition. However, this possibility is unlikely as, although the "oblique effect" has been established for direction discrimination, it does not occur for speed discrimination judgments (Matthews & Qian, 1999).

These two explanations still allow a role for a prior for smooth motion as differences between the thresholds in the crossed and uncrossed conditions can be attributed to grouping. However, the third explanation that we consider here negates the need for such a prior. Instead, participants may have the lowest speed discrimination thresholds in the uncrossed condition because they use "shearing" cues arising from the relative motion between the dots in the stimulus halves in the uncrossed condition. Verghese and McKee (2006) previously discounted this possibility as speed discrimination thresholds were unimpaired when introducing a gap between the two sets of dots to be discriminated. However, the potential role of shearing cues should be further tested in a large group of naïve participants.

Although shearing cues can explain the reduced sensitivity in the split condition compared to the crossed condition, another factor is needed to explain the even poorer performance in the split condition compared to the crossed condition. It is possible that humans are poorer at discriminating differences in speed between stimuli that follow different directions, compared to those that follow the same direction. To our knowledge, no research has explicitly tested this possibility although future research in this vein would allow greater insight into how speed and direction are represented in the brain.

The results presented here and by Verghese and McKee (2006) demonstrate that the spatial arrangement of stimuli is important for speed discrimination. Our results also show that spatial arrangement has a similar effect on the speed discrimination thresholds of typically developing children and children with autism as those of adults. Consistent with previous research (Ahmed et al., 2005; Manning et al., 2012; Manning et al., 2013), children have higher speed discrimination thresholds than adults, and children with autism are just as sensitive to speed differences as typically developing children. These results and those of Manning et al. (2013) suggest that speed discrimination is an aspect of motion processing that is unimpaired in children with autism, unlike other aspects of motion processing (Simmons et al., 2009). Such specificity suggests that motion processing atypicalities in autism are not pervasive as proposed by accounts such as the dorsal stream vulnerability (Braddick, Atkinson, & Wattam-Bell, 2003) and temporospatial processing disorders hypotheses (Gepner & Féron, 2009).

Contrary to our original hypotheses, children were *not* less affected by the experimental conditions than adults. Our original hypothesis was based on reduced grouping processes in children although it remains possible given the discussion above that grouping may not be the only factor at play. Likewise, our prediction that children with autism would be less affected by the experimental conditions (due to reduced grouping processes and/or reduced use of prior information) was not confirmed by the data. Future research is needed to understand the pattern of performance displayed by observers in this study and, in particular, to explain their markedly poor performance in the split condition.

However, it appears that both typically developing children and children with autism employ similar strategies as adults despite having reduced sensitivities to speed information overall.

Conclusion

Spatial arrangement clearly affects speed discrimination sensitivity in adults, typically developing children, and children with autism. However, our results question whether the best explanation for these effects is grouping. Instead, it could be that observers use shearing cues to improve speed discrimination and that speed discrimination is hindered when comparing across different directions. To hone in on the precise mechanisms, future research could benefit from repeating some of Verghese and McKee's (2006) other conditions in a large group of adult observers.

Keywords: speed discrimination, development, motion perception, grouping, autism

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