# THEORETICAL AND REVIEW ARTICLES

# The visual perception of motion by observers with autism spectrum disorders: A review and synthesis

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Traditionally, psychological research on autism spectrum disorder (ASD) has focused on social and cognitive abilities. Vision provides an important input channel to both of these processes, and, increasingly, researchers are investigating whether observers with ASD differ from typical observers in their visual percepts. Recently, significant controversies have arisen over whether observers with ASD differ from typical observers in their visual analyses of movement. Initial studies suggested that observers with ASD experience significant deficits in their visual sensitivity to coherent motion in random dot displays but not to point-light displays of human motion. More recent evidence suggests exactly the opposite: that observers with ASD do not differ from typical observers in their visual sensitivity to coherent motion in random dot displays, but do differ from typical observers in their visual sensitivity to human motion. This review examines these apparently conflicting results, notes gaps in previous findings, suggests a potentially unifying hypothesis, and identifies areas ripe for future research.

Autism is a pervasive developmental disorder that is characterized by a triad of symptoms: qualitative impairments in social interaction, delayed or impaired communication abilities, and stereotyped patterns of behavior or restricted interests (American Psychiatric Association [APA], 2006). In the psychological sciences, autism researchers have focused largely on the identification of and treatments for social and cognitive deficits. Visual perception provides an important source of information for both social and cognitive processes. Indeed, understanding how people with autism perceive their environments may be a necessary step toward understanding the social and cognitive deficits associated with autism. Consistent with this, substantial research has examined the relationships between autism and visual perception (see reviews by Behrmann, Thomas, & Humphreys, 2006; Dakin & Frith, 2005; Happé & Frith, 2006; Pellicano, Jeffery, Burr, & Rhodes, 2007; Schultz, 2005).

Within the last decade, numerous researchers have focused on the question of how observers with autism perceive movement, specifically, the movements of dot-defined surfaces and people. Initial studies reported that observers with autism show compromised visual sensitivity to coherently moving surfaces defined by randomly located dots but not to point-light displays (PLDs) of human movement. More recently, the opposite pattern of results has emerged, with reports of typical levels of visual sensi-

tivity to coherently moving random dot surfaces and significant deficits in visual sensitivity to coherent human motion. The goal of this review is to examine this increasingly complex literature and to suggest ways to integrate apparently divergent findings.

Because autistic disorders show substantial heterogeneity, the term *autism spectrum disorder* (ASD) is used to reflect this behavioral continuum. ASD is not incompatible with normal or superior intelligence (Schultz, 2005). Indeed, most studies of people with ASD are conducted with individuals whose intelligence falls within the average to above-average range. These include studies of people with Asperger's syndrome (AS) who experience deficits in social interaction and stereotyped or rigid behaviors in the absence of early language delay (APA, 2006; Wing, 2000). Many studies of ASD and AS include individuals with normal IQs, because those on the lower functioning end of the spectrum may have difficulty completing experimental tasks and often have comorbid disorders that complicate the implementation and interpretation of psychophysical performance.

## Local Processing Advantage in ASD During Form Perception

Extensive research suggests that ASD is associated with a certain perceptual style that includes supranormal local processing abilities (e.g., Frith, 1989; Jolliffe &

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Baron-Cohen, 1997; Shah & Frith, 1983, 1993). There is significant debate regarding whether this local processing advantage comes at the expense of global and configural processing (e.g., Dakin & Frith, 2005; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). A good example of the local advantage in ASD comes from performance on the embedded figures task. Individuals with ASD are able to detect static target shapes hidden within complex line designs much more rapidly than typically developed observers are (e.g., Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Because typically developed observers exhibit a more global or gestalt-like processing style, they generally analyze images in their entirety rather than focusing on the local elements that make up the images. As a result, typical observers are hindered, relative to observers with ASD, in their detection of embedded figures. Other examples of a local processing advantage in ASD include superior performance on the block design task (Shah & Frith, 1993), the reproduction of impossible figures (Mottron, Burack, Stauder, & Robaey, 1999), visual search (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998b), the ability to learn highly confusable patterns (Plaisted, O'Riordan, & Baron-Cohen, 1998a), and performance on tasks with Navon figures that are incongruent across local and global levels of analysis (Wang, Mottron, Peng, Berthiaume, & Dawson, 2007). Although observers with ASD are capable of processing visual information globally, their default perceptual setting is to process static images at the local level (Behrmann et al., 2006; Happé & Frith, 2006; Mottron et al., 2006).

The weak central coherence theory, an influential model of ASD, describes a processing bias for featural and local information accompanied by a relative failure to extract the gist or see the big picture in everyday life (Frith, 1989). Some researchers have highlighted the need for tasks that separately examine local and global processing (Happé & Booth, 2008). Consistent with this, recent updates of the weak central coherence theory emphasize the existence of a local processing advantage in addition to a global processing deficit (Happé & Frith, 2006). A reliance on local form processing by observers with ASD is also central to the enhanced perceptual functioning theory (Mottron & Burack, 2001; Mottron et al., 2006) that evolved from studies of an individual with AS who produced amazingly accurate drawings of three-dimensional objects (Mottron & Belleville, 1993). These studies suggested that high-functioning individuals with ASD rely heavily on low-level perceptual information to accomplish complex perceptual and cognitive tasks. In this theory, the local advantage does not necessarily imply a complete disruption of configural or global processes. Indeed, the typical global-to-local visual processing order has been found in perceptual tasks with high-functioning adolescents (Mottron et al., 1999) and with high- and low-functioning children (Deruelle, Rondan, Gepner, & Fagot, 2006; Ozonoff, Strayer, McMahon, & Filloux, 1994) with ASD. Despite empirical evidence of intact global processing abilities, individuals with ASD reliably demonstrate an automatic reliance on the local information in static visual stimuli (Mottron et al., 2006).
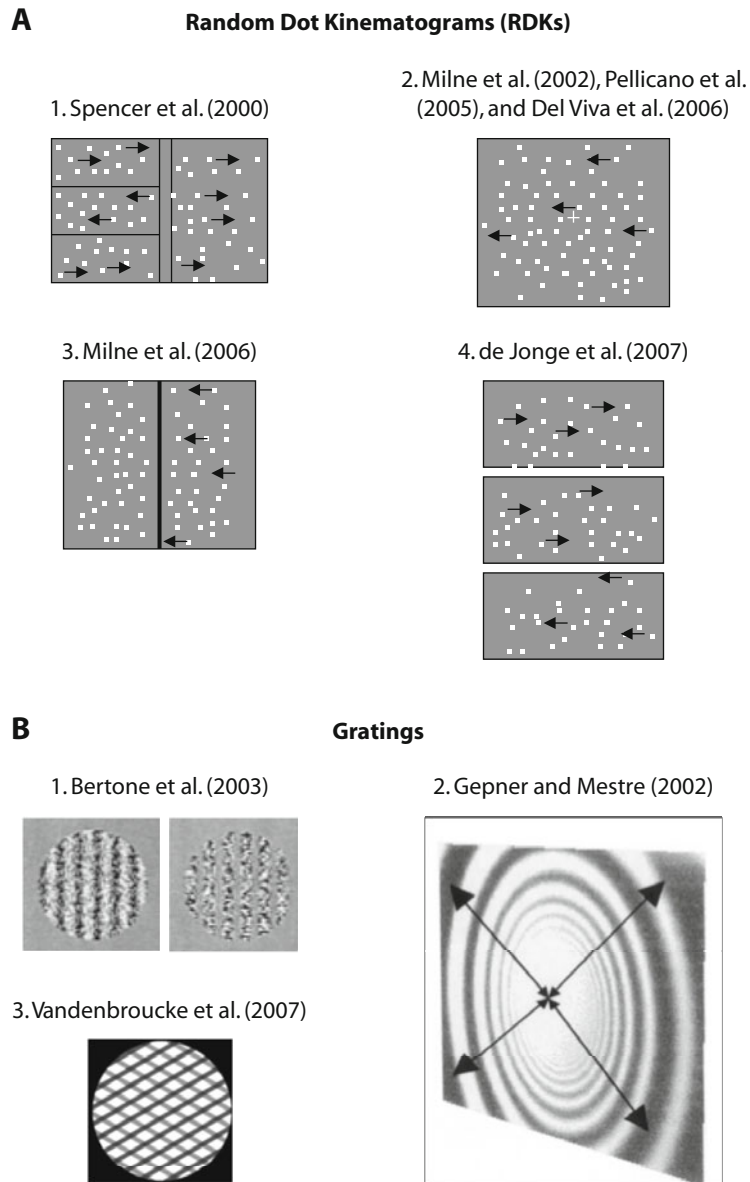
Do the local processing tendencies of observers with ASD extend to their visual perception of movement?

## Local Versus Global Motion Processing

As an inherently dynamic process, the visual perception of motion requires the integration of information over both space and time. Furthermore, because of a fundamental constraint in motion measurement known as the *aperture problem*, the visual perception of a moving object or surface requires the integration of information over disconnected regions of retinal space (Wallach, 1976). In this sense, motion perception under real-world conditions is fundamentally global. Yet, because *local* and *global* can be understood as two ends of a processing continuum, vision researchers routinely define the visual perception of a single moving point or contour as *local motion perception* and the perception of multiple points or contours moving relative to one another as *global motion perception* (e.g., Johansson, von Hofsten, & Jansson, 1980). In the lab, motion stimuli commonly are constructed to produce different percepts depending on whether each element is interpreted independently of (*locally*) or relative to (*globally*) other elements in an image (e.g., Shiffrar & Lorenceau, 1996). If observers with ASD default to local motion processes, observers with ASD should differ from typical observers in their visual percepts of such motion stimuli.

## Comparisons of Visual Motion Processing

The first published report suggesting that observers with ASD show deficits in their visual perception of motion involved a study of children's postural reactions to optic flow (Gepner, Mestre, Masson, & de Schonen, 1995). *Optic flow* refers to the pattern of dynamic information that is projected onto the retinae whenever individuals move through their environment (Gibson, 1950). Because specific patterns of locomotor activity produce specific patterns of optic flow, visual and motor processes are coupled such that large field optic flow typically triggers compensatory motor activity and postural adjustments in the observer. Although the neural mechanisms underlying optic flow perception by observers with ASD are unknown, part of the human MT+ complex known as *area MST* is strongly responsive during optic flow perception by typical observers (Smith, Wall, Williams, & Singh, 2006). In the study by Gepner et al., a small sample of children with ASD and age-matched control participants stood on a force plate positioned near a large screen. Projected onto that screen was a circular sinusoidal grating that, when set in motion, oscillated inward (*contraction*) and outward (*expansion*) at different speeds (Figure 1B-2). Across conditions, postural sway was recorded as participants closed their eyes or fixated the center of the grating while it was moving or static. Although the postural sway of typical children varied with perceived optic flow, optic flow had no significant impact on the postural sway of children with ASD. With caveats regarding the small sample size, the authors concluded that autism is associated with deficits in visual motion perception and in motoric responsiveness to environmental motion. Interestingly, observers with AS can exhibit larger than typical

**A**                    **Random Dot Kinematograms (RDKs)**

1. Spencer et al. (2000)

2. Milne et al. (2002), Pellicano et al. (2005), and Del Viva et al. (2006)

3. Milne et al. (2006)

4. de Jonge et al. (2007)

**B**                    **Gratings**

1. Bertone et al. (2003)

2. Gepner and Mestre (2002)

3. Vandenbroucke et al. (2007)

**Figure 1. Schematic illustrations of the stimuli used in studies of low-level visual motion perception by observers with autism spectrum disorder. (A) Random dot kinematograms. Although the arrangement of stimulus subregions and the specific stimulus judgments vary, all of these stimuli represent measures of visual motion coherence in otherwise nonstructured dot patterns. (B) Luminance and contrast gratings that have been used to measure perceived motion coherence. These included (1) first- and second-order motion, (2) optic flow stimuli, and (3) plaid patterns. Panel B-1 is from "Motion Perception in Autism: A Complex Issue?" by A. Bertone, L. Mottron, P. Jelenic, and J. Faubert, 2003, *Journal of Cognitive Neuroscience*, *15*, p. 223. Copyright 2003 by MIT Press. Reprinted with permission. Panel B-2 is from "Postural Reactivity to Fast Visual Motion Differentiates Autistic From Children With Asperger Syndrome," by B. Gepner and D. R. Mestre, 2002, *Journal of Autism and Developmental Disorders*, *32*, p. 234. Copyright 2002 by Springer-Verlag. Reprinted with permission. Panel B-3 is from "Coherent Versus Component Motion Perception in Autism Spectrum Disorder," by M. W. G. Vandenbroucke, H. S. Scholte, H. van Engeland, V. A. F. Lamme, and C. Kemner, 2007, *Journal of Autism and Developmental Disorders*, *38*, p. 942. Copyright 2007 by Springer-Verlag. Reprinted with permission.**

postural responses to optic flow (Gepner & Mestre, 2002; Price, 2006).

Subsequent research focused on the question of how observers with ASD integrate local motion signals over space. The most commonly adopted experimental technique that has been used to address this question is the measurement of motion coherence thresholds from arrays of randomly distributed dots known as *random dot kinematograms* (RDK; Figure 1A). Across trials, the percentage of dots that move together in the same direction, as if attached to a flat, rigid surface, is varied while the remaining dots move randomly. Motion coherence thresholds are determined by measuring the percentage of coherently moving dots required for accurate detection of coherent motion or for direction discrimination. Each dot typically has a limited lifetime so that the detection and interpretation of coherent motion requires a global integration of multiple motion signals. Usually, participants report with a buttonpress whether the coherent motion is in one direction or another (i.e., left vs. right or up vs. down) or which subregion of a display contains coherent motion. Because this psychophysical task has minimal verbal requirements, it is suitable for use with high-functioning individuals with ASD. In typical observers, perceived coherence is directly related to activity in area MT+ but not to activity in earlier visual areas (Rees, Friston, & Koch, 2000). To date, no study has investigated the neural areas involved in the visual perception of motion in RDKs in observers with ASD.

Spencer et al. (2000) were the first to demonstrate that children with ASD have higher motion coherence thresholds than typical children do (Table 1). In their study, observers indicated which of three rectangular subregions depicted dots that oscillated in opposite phase to the dots in a comparison stimulus (Figure 1A-1). In each of three age groups, children with ASD exhibited elevated motion coherence thresholds. Indeed, overall motion coherence thresholds were over 45% higher in children with ASD than in control participants. Because static form coherence thresholds were not elevated in these same children with ASD, these authors concluded that motion perception, per se, is compromised in ASD, possibly via dorsal stream deficiencies. More recent evidence indicates that static form coherence thresholds are also compromised in observers with ASD, raising the possibility of ventral stream deficits as well (Spencer & O'Brien, 2006; Tsermentseli, O'Brien, & Spencer, 2008).

Additional evidence in support of elevated motion coherence thresholds in young observers with ASD was provided by subsequent studies using a simplified RDK (Figure 1A-2). In the first of these, high-functioning children with ASD demonstrated a mean motion coherence threshold of about 25%, whereas typically developing children had a mean motion coherence threshold of about 15.3% (Milne et al., 2002). Using a similar paradigm, another laboratory found that children with ASD required an average of 22.4% of the dots in a display to translate coherently, whereas controls needed an average of 11.1% of the dots in a display to translate coherently in order to discriminate global direction (Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005). A similar pattern of results was reported

with RDKs presented for 1 sec (Davis, Bockbrader, Murphy, Hetrick, & O'Donnell, 2006). Furthermore, a recent study with a group of nonclinical adults found that high autistic traits were associated with elevated motion coherence thresholds (Grinter et al., in press). Finally, elevated motion coherence thresholds in observers with high-functioning autism (HFA), but not AS, have also been documented with *Glass patterns* (Glass, 1969), randomized dot arrays depicting correlated dot pairs (Spencer & O'Brien, 2006; Tsermentseli et al., 2008). In sum, the results of eight psychophysical studies (Davis et al., 2006; Gepner & Mestre, 2002; Gepner et al., 1995; Milne et al., 2002; Pellicano et al., 2005; Spencer & O'Brien, 2006; Spencer et al., 2000; Tsermentseli et al., 2008) converge in suggesting that the visual analysis of motion, whether in translating random dot patterns or expanding and contracting luminance gratings, is compromised in observers with ASD (Table 1). Because the perception of coherent motion in these random dot displays requires a global integration of motion information across many points, the threshold atypicalities described above may be consistent with a decreased reliance on global motion processes and/or an increased reliance on local motion processes.

Other researchers have suggested that the relationship between ASD and visual motion perception is more complex than the results above suggest. In an influential study by Bertone, Mottron, Jelenic, and Faubert (2003), young observers with ASD and control observers viewed two classes of stimuli (luminance defined and contrast defined) undergoing three categories of motion (translation, rotation, and radial motion). The stimuli were constructed by superimposing noise upon sinusoidally modulated gratings in one of two ways (Figure 1B-1). In the luminance-defined or first-order stimuli, motion signals were carried by edges that differed in luminance from their background. In the second-order stimuli, the moving edges were defined by luminance contrast (or texture) that was identical, overall, to that of their background. The perception of global direction in both of these stimulus types requires a global integration of motion signals. Percepts of first- and second-order motion differ, however, in several respects. For example, second-order stimuli produce weaker motion aftereffects (Cropper & Hammett, 1997), are more attention dependent (Derrington, Allen, & Delicato, 2004), and can require longer periods of temporal integration (Aaen-Stockdale, Ledgeway, & Hess, 2007) than first-order stimuli do. When participants in the study by Bertone et al. (2003) attempted to discriminate two directions of motion with the first-order stimuli, no performance differences were found between observers with and without ASD. Because many of the previously described studies used first-order stimuli, this result diverges from previous results. A motion perception deficit was found, however, with second-order motion stimuli, because observers with ASD demonstrated less perceptual sensitivity in the direction discrimination task than did control observers. Bertone et al. (2003) concluded that the deficits in visual motion processing associated with ASD are specific to the perception of complex motion.

**Table 1**
**A Summary of Psychophysical Studies That Have Been Conducted, to Date, on the Visual Perception of Low-Level Motion in Observers With Autism Spectrum Disorder (ASD)**

| Article | Stimulus | Motion | Speed (°/sec) | Stimulus Duration | Task | Participants With Autism | TD Controls Matched With ASD Participants On | Results |
|---|---|---|---|---|---|---|---|---|
| Gepner et al. (1995) | Radial sinusoidal gratings, 48 × 39 DVA | Radial & oscillatory | 0–100 | 1 min | Postural sway during grating oscillation | ASD: CA = 4–7, $N$ = 5 | CA: $N$ = 12 | ASD: Postural hyporeactivity |
| Spencer et al. (2000) | RDK: 30 × 22 DVA (2,000 dots) | Horizontal translation | 5.8 | Not reported | 2AFC motion coherence detection | ASD: CA = 7–11, $N$ = 23 | Verbal mental age: $N$ = 50, $N_{adults}$ = 19 | ASD: 46% higher motion coherence threshold overall |
| Gepner & Mestre (2002) | Large field, radial sinusoidal gratings, 51 × 45 DVA | Radial & oscillatory | 0–100 | 1 min | Postural sway during grating oscillation | ASD: CA = 7–11, $N$ = 3; AS: CA = 5–9, $N$ = 3 | CA: 5–12, $N$ = 9 | ASD: Postural hyporeactivity at high speeds AS: n.s. |
| Milne et al. (2002) | RDK: 224-msec dot lifetime (150 dots) | Horizontal translation | 8.8 | 1,010 msec | 2AFC direction discrimination with feedback | ASD: CA = 9–15, $N$ = 25 | CA & nonverbal IQ: $N$ = 22 | ASD: 63% higher overall threshold, 39% of observers had elevated thresholds |
| Bertone et al. (2003) | RDK: 5 DVA, 1st- and 2nd-order motion | Translation, rotation, & radial | 2 Hz, 1.57 rad/sec | 750 msec | 2AFC direction discrimination | ASD: Mean CA = 12, $N$ = 12 | CA, gender, & laterality: $N$ = 12 | ASD: 1st-order stimuli, n.s.; 2nd-order stimuli, decreased sensitivity to all motion types |
| Pellicano & Gibson (2008); Pellicano et al. (2005) | RDK: 30-msec lifetime, 18 × 14 DVA (100 dots) | Vertical translation | 6.3 | 600 msec | 2AFC direction discrimination with feedback | ASD: CA = 8–12, $N$ = 20 | CA, gender, laterality, & nonverbal ability: $N$ = 20 | ASD: 102% higher overall motion coherence threshold, 40% of observers with elevated thresholds |
| Davis et al. (2006) | RDK: 6.3 × 6.3 DVA (100 dots) | Horizontal translation | 6.36 | 220 msec & 1 sec | 2AFC direction discrimination | ASD: CA = 10–18, $N$ = 9 | CA & verbal ability: $N$ = 9 | ASD: 1-sec duration, higher overall threshold; 220-msec duration, n.s. |
| Del Viva et al. (2006) | RDK: 66-msec dot lifetime, 15 DVA (100 dots) | Translation, rotation, & radial | 10 | 160 msec | 2AFC direction discrimination | ASD: CA = 6–14, $N$ = 10 | CA & verbal MA: $N$ = 31 | n.s. |
| Milne et al. (2006) | RDK: 85-msec dot lifetime, 10 × 14 DVA panels with 300 dots | Horizontal translation | 7 | 1,010 msec | 2AFC coherence discrimination | ASD: CA = 8–13, $N$ = 23 | CA & nonverbal IQ: $N$ = 23 | n.s. overall 22% of participants had elevated thresholds |
| Spencer & O'Brien (2006) | Glass patterns 50-msec dot lifetime | Rotation | 5.8 | 250 msec | Locate circular target | ASD: Mean CA = 13, $N$ = 15 AS: Mean CA = 12, $N$ = 10 | CA & verbal IQ: $N$ = 15 | ASD: 88% higher overall threshold; AS: n.s. |
| de Jonge et al. (2007) | RDK: 5.7 DVA display | Horizontal translation | Not reported | Until response | 2AFC direction discrimination | ASD: CA = 7–33, $N$ = 29 | Mean CA, gender & IQ: $N$ = 32 | n.s. |
| Vandenbroucke et al. (2007) | Square-wave plaids, 11.6 DVA displays | Translation | 0.6–2.4 | 5 min | Report coherent motion percepts | ASD: CA = 16–29, $N$ = 13 | CA & IQ: $N$ = 27 | n.s. |
| Tsermentseli et al. (2008) | Glass patterns 50-msec dot lifetime | Rotation | 5.8 | 250 msec | Locate circular target | ASD: Mean CA = 28, $N$ = 10 AS: Mean CA = 23, $N$ = 11 | CA & IQ: $N$ = 20 | ASD: 113% higher threshold AS: n.s. |
| Takarae et al. (2008) | RDK: 100-msec dot lifetime; 7.5 DVA circular apertures | Translation | 3.3 | 300 msec | 2AFC coherence discrimination | ASD language delay: Mean CA = 16, $N$ = 37; ASD no delay: Mean CA = 15, $N$ = 27 | Mean CA & IQ: $N$ = 46 | ASD language delay: Elevated threshold compared to ASD no delay and TD controls |
| Price et al. (2009) | RDK (same as Milne et al., 2006), optic flow in VR | Horizontal translation; expansion | Variable | RDK: 1 sec; optic flow: 35 sec | 2AFC coherence discrimination; postural stability | AS: CA = 8–23, $N$ = 14 | Mean CA & IQ: $N$ = 16 | AS: Hyper-reactive to optic flow but no threshold elevation in motion coherence task |
| Grinter et al. (in press) | RDK: 6.48 DVA circular apertures | Radial translation | 5.4 | 426 msec | 2AFC coherence discrimination | — | High AQ: $N$ = 26 Low AQ: $N$ = 29 | High AQ: Elevated motion coherence thresholds |

Note—The stimuli include random dot kinematograms (RDKs), optic flow, and plaids. TD, typically developing; DVA, degrees of visual angle; CA, chronological age; 2AFC, two-alternative forced choice procedure; $N$, number of participants; AS, Asperger's syndrome; n.s., no significant difference in motion sensitivity; MA, mental age; VR, virtual reality; AQ, autism spectrum quotient.

Because overall performance with the first-order stimuli in the study by Bertone et al. (2003) was so high, one might wonder whether ceiling effects simply camouflaged the motion perception deficits documented by earlier researchers. Yet several more recent psychophysical studies have suggested that observers with ASD do not differ from typical observers in their perceptual sensitivity to first-order visual motion. In one such study (Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006), both children with ASD and matched controls viewed random dot displays (Figure 1A-2) in which varying percentages of dots traveled coherently in one of two directions while undergoing one of three motions (translational, rotational, or radial). The results of this study indicated no significant differences in the percentage of coherently moving dots needed for accurate direction discrimination by observers with ASD and either chronological age-matched or verbal mental age-matched control observers. A similar study with translating RDKs found no significant difference in motion coherence thresholds between young observers with ASD and matched control observers (de Jonge et al., 2007). Milne et al. (2006) found that observers with ASD did not significantly differ from matched control observers in their ability to report which of two RDKs (Figure 1A-3) contained coherent motion. Although Milne et al. (2002) and Milne et al. (2006) did differ in task type—namely, direction discrimination versus coherence discrimination—this methodological difference probably does not account for the differing results because findings of equal sensitivity and of sensitivity deficits have been reported with both types of tasks.

Finally, motion coherence has also been studied with plaid pattern stimuli that are defined by overlapping square-wave gratings (Figure 1B-3). These stimuli can be perceived as two component gratings sliding over each other in different directions or as a single coherently translating plaid. This latter percept requires an integration of motion signals across the component gratings—that is, global motion processes—and is strongly associated with neural activity in area MT+ of typical observers (Huk & Heeger, 2002). Young adults with ASD and controls demonstrated no significant differences in their perceptual interpretations of these bistable gratings (Vandenbroucke, Scholte, van Engeland, Lamme, & Kemner, 2007). Because typical observers and observers with ASD did not differ in the proportion of time they reported perceiving global plaid motion, these results are inconsistent with the hypothesis that observers with ASD default to local motion analyses more or to global motion analyses less than typical observers do.

### Interpreting Apparently Divergent Results

As the above summary and Table 1 make clear, substantial evolution has recently and rapidly taken place in our understanding of the visual perception of motion by observers with ASD. Several initial studies indicated that children with ASD are less able than controls are to integrate local motion signals for the visual detection and directional discrimination of coherent motion. Subsequent findings suggested that ASD-related motion perception deficits might be specific to the perception of second-order motion. More recently, several researchers have suggested that there may be no motion perception deficits associated with ASD. Because motion coherence thresholds with RDKs and the perception of coherent plaid patterns have long been assumed to reflect global motion processes, it is far from clear as to how these categorically different results can be interpreted in terms of a simple local motion bias with ASD. Recent research from another visual domain, static face perception, also seems to suggest that differences in the reliance on local and global form processes are insufficient to explain perception by observers with ASD. For example, a local processing bias does not explain why observers with ASD tend to look at mouths instead of eyes (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002). Nor does this explanation account for the finding that children with ASD demonstrate typical perceptual sensitivity to configural changes in the mouth but not the eye region (Wolf et al., 2008). So, what can we make of these vastly divergent results?

**Variability**. Variability in motion coherence thresholds is clearly central for understanding the above results. Milne et al. (2002; Milne et al., 2006) and Pellicano and colleagues (Pellicano & Gibson, 2008; Pellicano et al., 2005) have suggested that differences in motion coherence thresholds reflect variability within the ASD subject population. These researchers have noted that some of the children in their studies with ASD had thresholds that differed substantially from those of control children, whereas others did not. Commensurate with this suggestion is a report by Takarae and colleagues (Takarae, Luna, Minshew, & Sweeney, 2008) in which an ASD group with history of language delays demonstrated elevated motion coherence thresholds in comparison with an ASD group without history of language delay and typical controls. If children with ASD differ in the presence of global motion deficits, averaging data across participants with and without deficits would account for some of the variability found in this literature.

**Stimulus complexity**. Bertone et al. (2003) have argued that stimulus complexity determines the presence of motion perception deficits such that motion deficits are associated with contrast-defined or second-order motion but not with luminance-defined or first-order motion. Because the perception of contrast-defined, or second-order, motion involves patterns of neural activity that differ from those found during the perception of luminance-defined motion (Smith, Greenlee, Singh, Kraemer, & Henning, 1998), Bertone et al. (2003) concluded that observers with ASD are selectively compromised in their perception of complex motion. Later work with typical observers suggested that motion complexity, or the perceptual difference between first- and second-order motion, is most apparent when observers are 6 years of age or younger (Bertone, Hanck, Cornish, & Faubert, 2008). Unfortunately, simplicity and complexity are difficult terms to define. For example, it is not obvious how the RDKs (Figure 1) used in the direction and coherence discrimination tasks that have identified significant motion deficits in ASD (Davis et al., 2006; Milne et al., 2002; Pellicano et al., 2005;

Spencer et al., 2000) are more complex than the RDKs used in tasks that identified no such deficits (de Jonge et al., 2007; Del Viva et al., 2006; Milne et al., 2006).

**Attention**. Another challenge to the hypothesis that motion-processing deficits in ASD are specific to second-order motion is presented by the finding that neural responses to first- and second-order motion do not differ as much as originally had been assumed (Seiffert, Somers, Dale, & Tootell, 2003). Dakin and Frith (2005) have argued that visual attention provides a better explanation of the findings by Bertone et al. (2003), since the visual perception of second-order motion shows a greater dependence on attentional processes than does the perception of first-order motion (Cavanagh, 1992). Indeed, observers with ASD distribute their attentional resources differently (Burack, 1994; O'Riordan, 2004; Plaisted et al., 1998b) and exhibit differences in oculomotor function (Brenner, Turner, & Müller, 2007) relative to typically developing observers. Even in typical observers, attention modulates the perception of coherent motion in random dot patterns (Liu, Fuller, & Carrasco, 2006). Thus, attentional and oculomotor differences may help to explain differences in the visual analysis of first- and second-order motion stimuli by observers with ASD (for a review, see Milne, Swettenham, & Campbell, 2005).

**Stimuli**. Deficits in visual sensitivity to motion as a function of speed, especially high speeds, have been proposed previously for observers with ASD (Gepner & Mestre, 2002). Yet speed does not appear sufficient to account for the differences in motion coherence thresholds summarized here because there is considerable overlap in the ranges of speeds used in studies that did and did not find significant differences (see Table 1). Nonetheless, Gepner and colleagues (Gepner & Mestre, 2002; Gepner et al., 1995) did use speeds with their optic flow stimuli that were substantially faster than the speeds that have been used with RDKs.

Others have posited that stimulus duration might be a critical factor because performance with brief stimulus durations requires greater reliance on memory and attentional processes that might be compromised in ASD (de Jonge et al., 2007). Furthermore, long duration stimuli may allow for the use of compensatory strategies by individuals with ASD. Importantly, however, significant deficits in motion processing have been found with online measures of postural responsivity to optic flow (Gepner & Mestre, 2002; Gepner et al., 1995; Price, 2006) that are largely, if not completely, independent of memory processes and high-level compensatory strategies. Moreover, Davis et al. (2006) reported motion coherence deficits in observers with ASD at long (1 sec) but not short (220 msec) stimulus durations.

Still others have proposed that differences in visual sensitivity to coherent motion may reflect differences in the spatial frequency content of stimuli (Vandenbroucke et al., 2007). For example, previously used luminance contrast stimuli (Bertone et al., 2003) and plaid stimuli (Vandenbroucke et al., 2007) have lower spatial frequency content than random dot patterns do. But again, studies with very similar random dot patterns (Table 1) have produced diver-

gent results. Thus, to date, differences in stimulus features across studies do not provide any obvious explanations for the diversity of results in studies of motion perception by observers with ASD.

**Participant age**. Nearly all studies of the relationship between ASD and visual motion perception have used child and adolescent participants. This age range is important because motion coherence thresholds typically change during development. In typically developing observers, motion coherence thresholds drop with increases in age up to adolescence. By 3 months of age, infants typically demonstrate visual sensitivity to translation direction (Wattam-Bell, 1994) and contraction (Shirai, Kanazawa, & Yamaguchi, 2006) in random dot patterns in which 50% of the dots move together coherently. Between the ages of 7 and 9 years, typical observers can detect coherent motion in random dot displays when approximately 20% of the dots move coherently (Gunn et al., 2002; Raymond & Sorensen, 1998; Spencer et al., 2000). By 10 years of age, typical observers demonstrate motion coherence thresholds that do not differ from adult thresholds (Spencer et al., 2000). It is important to note that absolute thresholds vary as a function of stimulus conditions. For example, in typically developed adults, motion coherence thresholds range from 5% to 25% depending on stimulus conditions (Raymond & Sorensen, 1998). Furthermore, simplification of stimulus conditions can render age-related differences on motion coherence tasks more difficult to detect (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Parrish, Giaschi, Boden, & Dougherty, 2005). Given the importance of developmental changes in the visual perception of coherent motion, it is critically important for studies of observers with ASD to include chronologically age-matched control observers. As indicated in Table 1, researchers routinely do just this.

Although children with ASD and typically developing children both show decreasing motion coherence thresholds with increasing age (Del Viva et al., 2006; Spencer et al., 2000), this trend appears to be more pronounced for observers with ASD. This raises the possibility that at least some young observers with ASD may reach typical motion coherence thresholds in adulthood. To date, only a few studies of the relationships between motion coherence thresholds and ASD have included adult participants. With Glass pattern stimuli, which, unlike random dot stimuli, are locally oriented, adult observers with HFA show elevated motion coherence thresholds relative to typical controls, whereas adult observers with AS do not (Tsermentseli et al., 2008). Furthermore, Atkinson (in press) recently reported that adults with ASD are less accurate than typical controls at detecting coherent motion in RDKs. In another study, children with ASD judged motion coherence differently from age-matched controls, whereas young adults with ASD did not (de Jonge et al., 2007). Thus, some adults on the autism spectrum either achieve typical levels of visual motion sensitivity or develop compensatory mechanisms that allow them to perform as well as controls do in measures of motion coherence.

**Control groups**. Lastly, the characterization of control groups is critical in any study comparing individuals

with and without ASD. Most of the previously described studies matched experimental groups on scales of intelligence. Usually, ASD and control groups exhibit average intelligence as measured by either the Wechsler scale or the Raven matrices. Although both of these measures are designed to assess intelligence accurately and are assumed to function interchangeably, recent evidence suggests that this may not always be the case; for example, the Raven scales assess intelligence 30 percentiles above the Wechsler scales for individuals without language problems (Dawson, Soulières, Gernsbacher, & Mottron, 2007). This finding highlights just one of the difficulties in comparing data across different experimental groups.

Another fundamental issue concerns the identification of appropriate matching criteria. For instance, monkeys frequently produce lower motion coherence thresholds with RDKs than typical adult human observers do (e.g., Britten, Shadlen, Newsome, & Movshon, 1992). Inferior human performance is likely a function of motivation. Nonetheless, this raises the question of whether measures of intelligence provide the optimal matching criteria for psychophysical tests of perceived motion coherence. Consistent with this, studies that have specifically investigated individual differences among observers with ASD in their perception of RDKs have found no significant relationship between either verbal or nonverbal IQ and thresholds for the perception of coherent motion (Atkinson, in press; Milne et al., 2006; Pellicano & Gibson, 2008).

Recent evidence suggests that observers' motor skills may be a particularly important matching factor in studies of visual motion coherence. Milne et al. (2006) reported that performance on tasks requiring fine motor control correlated with visual motion coherence thresholds in both observers with ASD and controls. Similarly, motor scores on the Dean–Woodcock correlate with visual motion coherence thresholds in observers with AS (Price, Shiffrar, & Kerns, 2009). The potential importance of motor skills as a matching factor in studies of movement perception will be revisited in the discussion of visual sensitivity to PLDs of human motion.

**Different clinical groups**. Some aspects of motion perception appear to vary across different clinical subpopulations within the autism spectrum. For example, there is converging evidence that, at least for children and young adults, individuals with AS differ from those with ASD in their postural responses to optic flow (Gepner & Mestre, 2002; Price et al., 2009). Other evidence suggests that, during the perception of locally oriented Glass patterns, children with AS do not exhibit decrements in motion coherence or form detection thresholds, whereas children with HFA do (Spencer & O'Brien, 2006). The same pattern holds true for adult observers with AS and HFA (Tsermentseli et al., 2008). It remains to be seen whether observers with AS differ from observers with HFA in their perception of motion coherence in RDKs. Because different screening measures can lead to different diagnoses of AS or ASD (e.g., Johnson, Myers, & Council on Children With Disabilities, 2007), diagnostic heterogeneity between subjects might contribute to some of the variability of results across studies.

**Neurophysiological implications**. Many researchers have used the psychophysical tasks described above to hypothesize about the potential neural underpinnings of motion perception deficits. Originally, researchers interpreted atypicalities in visual sensitivity to coherent motion as evidence for damage to the dorsal pathway (e.g., Pellicano & Gibson, 2008; Pellicano et al., 2005; Spencer et al., 2000; for a review, see Laycock, Crewther, & Crewther, 2007). Given that area MT+, which receives substantial input from the magnocellular pathway, is essential for the detection of coherent motion (Britten et al., 1992), it is tempting to conclude from these studies that deficits in area MT+ might be responsible for some of the deficits found on motion coherence tasks. But no study to date has examined neural activity in observers with ASD during the perception of RDKs. Moreover, when the entirety of the data is considered across experiments (Table 1), the relationship between dorsal pathway function and ASD becomes unclear. Recent evidence has also challenged the integrity of the ventral pathway in observers with ASD (Spencer & O'Brien, 2006; Tsermentseli et al., 2008). Thus, the hypothesis that motion perception by observers with ASD can be fully understood as reflecting an automatic default to local motion processes, possibly as a result of some dysfunction in the dorsal stream, is supported by some, but certainly not all, of the studies that have been completed to date.

Dakin and Frith (2005) proposed another neurophysiological model, that observers with and without ASD may differ in their visual analyses of movement as a result of differences in the superior temporal sulcus (STS), an area located at an intersection of the dorsal and ventral pathways (Baizer, Ungerleider, & Desimone, 1991). The structure and function of the STS are compromised in observers with ASD (e.g., Boddaert et al., 2004; Zilbovicius et al., 2006). As Dakin and Frith noted, in typical observers, neural activity in the STS is modulated by the speed of dot stimuli (Grossman et al., 2000) and shows more activity during the perception of second-order than first-order motion (Noguchi, Kaneoke, Kakigi, Tanabe, & Sadato, 2005). If ASD-related dysfunction in the STS is responsible for decreased visual sensitivity to random dot stimuli, then variable experimental results would be expected, since the STS is only weakly responsive to random dot motion (Grossman et al., 2000). Although the STS's responses to RDKs may be small, this area is strongly responsive to PLDs of human movement and social action (for a review, see Blake & Shiffrar, 2007). Indeed, it has been argued that the posterior STS (STSp) is optimally tuned for the detection of human motion (Pyles, Garcia, Hoffman, & Grossman, 2007). If, as Dakin and Frith argued, STS dysfunction is responsible for the ambiguous motion coherence results reported above, then one would expect to find robust deficits in visual sensitivity to human movement in observers with ASD.

### The Visual Perception of Body Movement

Typical newborn observers appear to be predisposed for the visual perception of human movement. Only 2 days after birth, infants preferentially attend to canonical biological motion relative to inverted biological motion or

random motion in PLDs (Simion, Regolin, & Bulf, 2008). Perceptual sensitivity to human motion, per se, increases through infancy and into late childhood. For example, 3-month-old infants demonstrate equivalent levels of visual sensitivity to temporal phase differences in point-light human and animal motions, whereas 5-month-old infants respond only to phase differences in upright human motion, suggesting that the typical visual system becomes tuned for the detection of canonical human motion (Pinto, 2006). Perceptual sensitivity to unmasked PLDs of human movement approaches adult levels in observers as young as 5 years of age (Blake, Turner, Smoski, Pozdol, & Stone, 2003; Pavlova, Krägeloh-Mann, Sokolov, & Birbaumer, 2001). When masks are added to PLDs of human motion, typical detection thresholds decrease significantly across the ages of 6 years, 9 years, and adulthood (Freire, Lewis, Maurer, & Blake, 2006). In adulthood, typical observers exhibit greater visual sensitivity to human motion than to animal motion (Pinto & Shiffrar, 2009) or object motion (Kaiser, Fermano, & Shiffrar, 2008; Shiffrar, Lichtey, & Heptulla-Chatterjee, 1997).

In typical observers, the patterns of perceptual sensitivity described above correlate with levels of neural activity in the STSp during the perception of PLDs of human and animal movement (Lichtensteiger, Loenneker, Bucher, Martin, & Klaver, 2008; Pyles et al., 2007). STSp activity becomes increasingly tuned to the perception of human movement relative to object movement in typical children (Carter & Pelphrey, 2006) but not in young observers with ASD (Pelphrey & Carter, 2008).

Moore, Hobson, and Lee (1997) conducted the first behavioral studies of the visual perception of PLDs of human movement by observers with ASD (Table 2). In their studies, children and adolescents with ASD or nonautistic retardation viewed variable-duration movies of people and objects in motion. These movies were constructed with the classic point-light technique (Johansson, 1973), in which markers or point-lights are attached to the major joints or corners of moving people and objects and then recorded so that only the point-lights are visible in the resultant movies (Figure 2). Because so much form information is removed during the construction of these stimuli, they are commonly used to isolate motion perception processes. Moore et al. found no significant differences in the amount of time that children with ASD and controls needed to accurately describe point-light movies of human movement. There was, however, a trend for children with ASD to have difficulty recognizing human movement when it was defined by five point-lights and presented for less than 1 sec. Autistic children were also less likely than controls to describe the emotional states (e.g., happy, sad), but not the actions (e.g., walking, running), depicted in PLDs of human action. The same pattern of results has been reported with children with ASD (Parron et al., 2008) and with adolescents and adults with HFA and AS (Hubert et al., 2007). These groups of researchers concluded that observers with ASD exhibit normal visual sensitivity to human movement, per se, but impairments in the attribution of mental states to human movement. However, because ASD is associated with language deficits (APA, 2006), performance by observers with ASD in these studies may reflect communication deficits more than perceptual processes. Furthermore, the free report measures used in these studies can be unreliable, because they are influenced by expectancy, attention, and motivation (Blake et al., 2003). Yet, when observers were asked to label emotions and actions in a forced choice recognition task, emotion recognition was impaired in an ASD group (Atkinson, in press), supporting the results of earlier verbal response studies (Hubert et al., 2007; Moore et al., 1997; Parron et al., 2008). Notably, elevated motion coherence thresholds correlated with impaired recognition of the emotion in PLDs of human movement. In contrast to the earlier studies, though, the ASD group also revealed deficits in labeling actions in PLDs. This finding suggests that an emotion-processing deficit may not fully describe the perception of human action in this population. Nonetheless, these studies clearly demonstrate that observers with ASD can detect and identify human motion in PLDs.
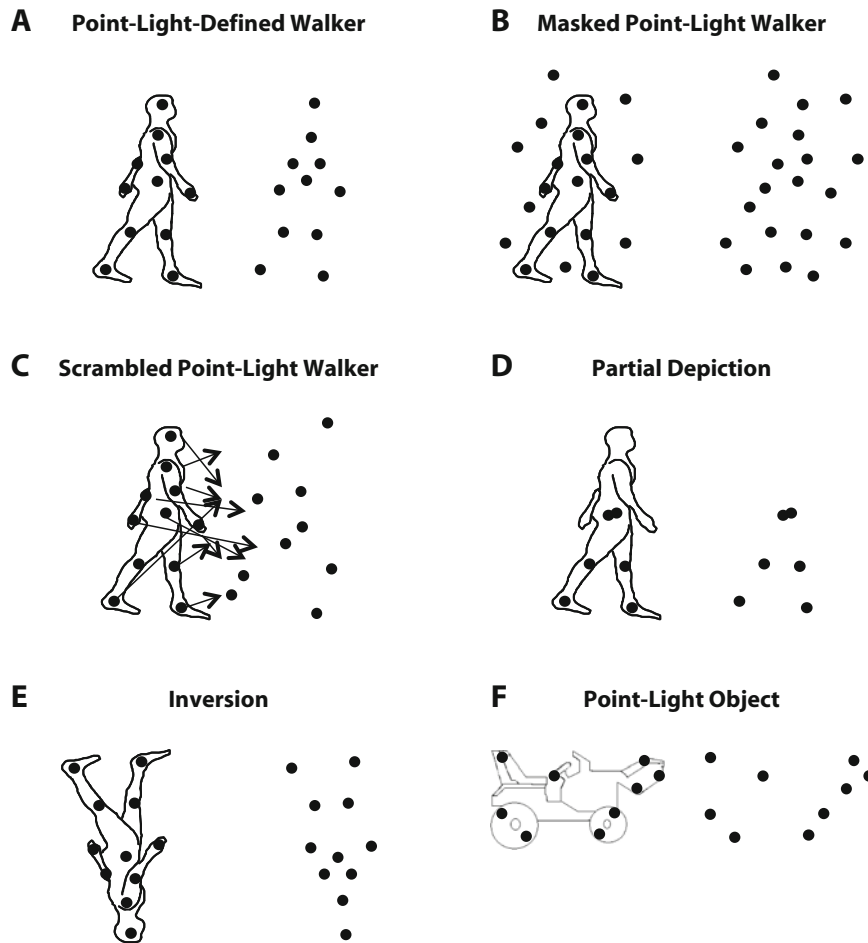
But do observers with and observers without ASD use the same neural mechanisms to perceive PLDs of human movement? This question has been addressed in recent brain imaging research. In one study, observers with AS and matched controls viewed coherent and scrambled displays of a point-light person walking on a treadmill and reported whether the walker faced and walked to the right or left (Herrington et al., 2007). Generally speaking, when point-light walkers are scrambled, the starting positions of all of the walker's points are randomly relocated (Figure 2C). If no other changes are made, coherent and scrambled point-light walker stimuli differ in the presence of the global hierarchical structure of the human body but not in the number, size, luminance, or velocity profiles of the moving points. In the study by Herrington et al., even though participants with AS and controls both demonstrated ceiling levels of direction discrimination performance, fMRI measures indicated significantly less neural activity in the superior temporal region, encompassing both the human MT+/V5 area and the STS, in participants with AS than in controls. Areas MT+ and STS are highly interconnected in monkeys (e.g., Weller, Wall, & Kass, 2004) and neurotypical humans (e.g., Bradley, 2001), which might explain the coupled decrease in activity in these areas. Activity in the superior temporal sulcus is required for the accurate perception of PLDs of human motion (Grossman, Battelli, & Pascual-Leone, 2005; Saygin, 2007). Thus, decreased neural activity in this region supports the hypothesis that observers with AS differ from typical observers in their visual analyses of human action.

Freitag et al. (2008) used fMRI and several behavioral measures to examine the relationships between ASD, motor skills, imitation, and visual analyses of human movement. Observers with ASD and controls passively viewed scrambled and coherent PLDs of human gait while being scanned. Outside the scanner, participants completed a point-light walker coherence discrimination task with the same stimuli. Although task performance was at ceiling both for observers with ASD and for controls, the fMRI data revealed differences in STSp activity between observers with and without ASD. Interestingly, neural activity during the perception of coherent point-light walk-

**Table 2**
**A Summary of Psychophysical Studies That Have Been Conducted, to Date, on the Visual Perception of Point-Light Displays (PLDs) of Human Movement by Observers With Autism Spectrum Disorder (ASD)**

| Article | Stimulus | Motion | Speed (°/sec) | Stimulus Duration | Task | Participants With Autism | Controls TD, Unless Otherwise Noted, and Matched On | Results |
|---|---|---|---|---|---|---|---|---|
| Moore et al. (1997) | PLDs (5–10 points) | Human body & objects | Variable & typical | 40–5,000 msec | Describe each PLD RT = DV | ASD: CA = 11–19, N = 17 | Mentally retarded, CA, & BVPS: N = 17 | ASD: Disrupted emotion perception, n.s.: Action perception |
| Blake et al. (2003) | PLDs (9 points) | Human body actions | Variable, average = 4 | 1 sec | 2AFC coherence discrimination | ASD: CA = 8–10, N = 16 | MA: N = 9 | ASD: Decreased sensitivity to coherent human motion |
| Klin et al. (2003) | PLDs (16 points, upright & inverted) | Human body actions with sounds | Variable & typical | Extended | Preferential looking paradigm | ASD: Mean CA = 2, N = 5 | CA: N = 6 | ASD: No preference for canonical human motion |
| Herrington et al. (2007) | PLDs (13 points) | Human gait | Variable & typical | 1 sec | 2AFC direction discrimination | AS: Mean CA = 28, N = 10 | CA & IQ: N = 10 | AS: Less neural activity in superior temporal area n.s.: Direction discrimination |
| Hubert et al. (2007) | PLDs (5–10 points) | Human body & objects | Variable & typical | 5 sec | Describe each PLD | AS & HFA: CA = 15–34, N = 19 | CA & gender: N = 19 | ASD: Disrupted emotion perception n.s.: Action perception |
| Freitag et al. (2008) | PLDs (15 points) | Human gait | Variable & typical | 1.5 sec | 2AFC coherence discrimination RT = DV | ASD: Mean CA = 18, N = 15 | CA, gender, & IQ: N = 15 | ASD: Different neuronal responses during gait perception n.s.: RT to human gait |
| Parron et al. (2008) | PLDs (5–10 points) | Human body & objects | Variable & typical | 5 sec | Describe each PLD | ASD: CA = 7–18, N = 23 | CA & gender: N = 23 | ASD: Disrupted emotion perception n.s.: Action perception |
| Klin & Jones (2008) | PLDs (16 points, upright & inverted) | Human body actions with sounds | Variable & typical | 30-sec mean | Preferential looking paradigm | ASD: 15-month-old infant, N = 1 | 9-month old, verbal MA: N = 1 CA & MA: N = 1 | ASD: No preference for canonical human motion |
| Kaiser et al. (2008) | PLDs (9 points) | Human body & objects | Variable & typical | 5 sec | 2AFC coherence discrimination | AS & HFA: Mean CA = 20, N = 6 | Mean CA: N = 32 | ASD: Equal sensitivity to human and object motion TD: Greater sensitivity to human motion |
| Price et al. (2009) | PLDs (6 points, lower half of body) | Human gait, legs and feet only | Variable & typical | 5 sec | Gait coherence & typicality discriminations | AS: CA = 8–23, N = 14 | Mean CA & IQ: N = 16 | AS: Decreased sensitivity to gait coherence and typicality |
| Klin et al. (2009) | PLDs (16 points, upright & inverted) | Human body actions with sounds | Variable & typical | 30.5-sec mean | Preferential looking paradigm | ASD: Mean CA = 2, N = 21 | TD: CA & MA, N = 39 DD: CA & verbal MA, N = 16 | ASD: No preference for canonical human motion |
| Atkinson (in press) | PLDs (13 points) | Human body actions & emotions | Variable & typical | 3 sec | Forced choice labeling | ASD: Mean CA = 30.9, N = 13 | Mean CA & IQ: N = 16 | ASD: Disrupted action and emotion recognition |

Note—TD, typically developing; RT, reaction time; DV, dependent variable; CA, chronological age; N, number of participants; BVPS, British Picture Vocabulary Scale; n.s., no significant difference in motion sensitivity; 2AFC, two-alternative forced choice procedure; MA, mental age; AS, Asperger's syndrome; DD, developmentally delayed.

**A    Point-Light-Defined Walker**

**B    Masked Point-Light Walker**

**C    Scrambled Point-Light Walker**

**D    Partial Depiction**

**E    Inversion**

**F    Point-Light Object**

**Figure 2. Schematic illustrations of the stimuli used in studies of the visual perception of human movement by observers with autism spectrum disorder. Each stimulus is depicted in two ways. On the left, the stimulus is shown with the outline of the human body for ease of comprehension. These outlines were not used as experimental stimuli. On the right is a static illustration of one frame of a point-light movie.**

ers correlated with behavioral measures of each observer's imitation ability and gross motor skills.

The fMRI measures from the last two studies suggest that observers with ASD and controls employ different neural mechanisms during the visual analysis of human movement. Consistent with this, several behavioral studies using rigorous psychophysical measures have reported atypicalities in visual sensitivity to human movements by observers with ASD. In the first such study, Blake et al. (2003) assessed visual sensitivity to PLDs of human movement with a two-alternative forced choice procedure. On half of the trials, observers viewed brief point-light movies of a person performing some action such as running, throwing, or jumping. On the other half of the trials, the starting locations of the points were temporally scrambled to disrupt the hierarchy of pendular motions that define the human body. Children viewed these point-light movies in random order and verbally reported whether the dots moved like a person. As a control for visual grouping processes, these same observers also performed a global form detection task by pointing to the location of a static circle created by an alignment of oriented line segments among an array of distractor line segments. Children with ASD performed the human motion detection task more poorly than matched controls did, but they performed the form detection task as well as controls did. Furthermore, a significant correlation was found between the severity of a child's autism and that child's performance on the human motion detection task. These researchers concluded that children with ASD are selectively compromised in their ability to perceive coherent human motion. However, these data are subject to alternative interpretations. Given the diagnostic language and communication impairments in ASD (APA, 2006), children with ASD may have performed relatively poorly on the human motion task compared with the form task, because the first required a verbal response, whereas the second did not. Furthermore, because a static control task was used, the results of this experiment are consistent with the hypothesis that observers with ASD show deficits in global motion processing in general, and not specifically in human motion processing. Finally, observers may have relied on low spatial frequency information

in the static task but not in the motion task (Dakin & Frith, 2005). Thus, it is difficult to determine conclusively from these data whether observers with ASD exhibit a selective deficit in the visual analysis of human motion.

Other evidence suggests that observers with ASD may have less visual experience watching other people move. In a series of preferential looking studies, young children viewed movies of a point-light person, shown upright on one side of a screen and inverted on the other side of the screen, with a sound track consistent with the upright point-light action. Stimulus inversion usually decreases visual sensitivity to PLDs of human motion (e.g., Bertenthal & Pinto, 1994). Typically developing toddlers demonstrate a clear looking preference for canonically oriented point-light actions, whereas toddlers (and a 15-month-old infant) diagnosed with autism do not (Klin & Jones, 2008; Klin, Jones, Schultz, & Volkmar, 2003; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). Visual experience influences sensitivity to human movement (Jacobs, Pinto, & Shiffrar, 2004). Thus, typical observers who preferentially attend to human motion would gain more visual experience with it, and that, in turn, would enhance their sensitivity to human movement. Meanwhile, observers lacking such a preference, such as the children with ASD in the studies by Klin and colleagues (Klin & Jones, 2008; Klin et al., 2003; Klin et al., 2009), would gain less visual experience with human movement and, as a result, experience less sensitivity to human motion. One complication, however, is that inverted displays of human movement appear less coherent than upright displays do (e.g., Shiffrar et al., 1997; Sumi, 1984). Thus, an alternative interpretation is that, relative to children with ASD, typical children are more likely to preferentially attend to any coherent motion.

A recent study examined whether ASD-related deficits in visual sensitivity to PLDs of human movement can be attributed to global deficits in visual motion processing (Kaiser et al., 2008). In this study, observers with ASD and chronological-age-matched controls performed a coherence discrimination task with point-light depictions of human motion and tractor motion (Figure 2F). The stimuli were either coherent or positionally scrambled and appeared within a dot mask constructed by scrambling the locations of a duplicate stimulus (Figure 2C). Masking provided two benefits: First, it increased task difficulty as an insurance against ceiling effects. Second, because the same points with the same velocity trajectories defined both the target (human or tractor) and the mask, the perception of any single point could not be used to determine target coherence. Instead, global motion processes were required, because only the global structure defined by multiple points could be used to differentiate the target from the mask. In both conditions, observers reported by pressing one of two buttons whether they detected coherent motion. Although typical observers demonstrated greater visual sensitivity to human motion than to tractor motion, observers with ASD were equally sensitive to both categorizes of motion. This pattern of results suggests that observers with ASD experience a deficit in their visual sensitivity to human motion that is independent of their visual sensitivity to coherent motion in general.

## Integrating the Motion Percepts of Random Dots, Gratings, and Bodies in ASD

Of all of the divergent results described above, the issue of individual differences in visual motion sensitivity among individuals with ASD remains the most intriguing. What might be the critical variables that differentiate observers with typical motion sensitivity thresholds from those with atypical thresholds? Gepner and Mestre (2002) suggested that visual motion perception deficits might be related to, or result from, deficits in the linkage between the visual and motor systems. Consistent with this proposal, Milne et al. (2006) found a significant relationship between visual motion coherence thresholds with RDKs and fine motor control in children with ASD and matched controls. In observers with AS, Dean–Woodcock measures of motor system function correlate with visual sensitivity to coherent motion in random dot displays and PLDs of human motion (Price, 2006; Price et al., 2009). Finally, neural activity in area STS during the observation of point-light depictions of human movement correlates with gross motor skills in observers with ASD (Freitag et al., 2008). Taken together, these interdependent findings suggest that individual differences in motor abilities may explain a significant amount of the variability in visual sensitivity to movement among observers with ASD.

What aspects of motor system functioning might influence visual sensitivity to movement? In recent years, several groups have focused on the functionality of the mirror neuron system (MNS) in observers with ASD (e.g., Dapretto et al., 2006; Gallese, 2006; Iacoboni & Dapretto, 2006; Nishitani, Avikainen, & Hari, 2004; Oberman & Ramachandran, 2007; Williams, 2008; Williams, Whiten, & Singh, 2004). The MNS is located in the central premotor cortex (area F5) in the macaque (Rizzolatti, Fogassi, & Gallese, 2001) and in Brodmann areas 44 and 45 in the human (Iacoboni et al., 1999), and it receives input from the STS (e.g., Pineda, 2008). Significant correlations have been found between atypical cortical thinning in MNS areas and ASD symptom severity (Hadjikhani, Joseph, Snyder, & Tager-Flusberg, 2006). In EEG measures of MNS function, typical observers show significant mu suppression during the observation of other peoples' movements, whereas observers with ASD do not (Oberman et al., 2005). To the extent that the MNS links the production and perception of actions (Rizzolatti & Craighero, 2004), these and other results are consistent with the hypothesis that ASD involves dysfunction of the MNS (see Williams, 2008, for a recent review).

Other researchers, however, dispute the claim that dysfunctions of the MNS are involved in the social and perceptual difficulties associated with ASD (e.g., Leighton, Bird, Charman, & Heyes, 2008). For example, whereas imitation is thought to rely on MNS function (e.g., Iacoboni, 2005; Iacoboni et al., 1999), a recent study found equivalent levels of performance on four different imitation tasks by observers with ASD and by controls (Hamilton, Brindley, & Frith, 2007).

Action perception and action production obviously involve neural mechanisms other than, or in addition to,

the MNS. Nonetheless, the MNS is part of the motor system, and ASD is associated with motor difficulties including clumsiness (Burgoine & Wing, 1983; Wing, 1981), atypical posture (Burgoine & Wing, 1983), deviant reach-to-grasp movement (Mari, Castiello, Marks, Marraffa, & Prior, 2003), abnormal gait (e.g., Hallett et al., 1993; Jansiewicz et al., 2006; Rinehart et al., 2006), and compromised manual dexterity, balance, and ball skills (Manjiviona & Prior, 1995). Such motor difficulties, regardless of whether they depend on MNS damage, would necessarily limit one's ability to link one's visual percepts of another person's actions with one's own motor repertoire (e.g., Serino et al., in press). To the extent to which movement perception relies on the processes underlying movement production, and conversely, movement production relies on movement perception, disruption of perception–action coupling should give rise to decrements in the ability to perceive and produce movement. It follows that matching participants on motor ability should reduce some of the variability in measures of visual sensitivity to movement.

## Conclusions

Social impairment is widely considered to be the fundamental deficit in ASD. Numerous researchers have investigated whether perceptual deficits might be the ultimate cause of some social impairment (e.g., Schultz, 2005). Movements of the human body carry a surprising amount of social information. For example, from the information available in PLDs, typical observers can detect a walking person's emotional state (Atkinson, Dittrich, Gemmell, & Young, 2004), gender (Pollick, Kay, Heim, & Stringer, 2005), identity (Loula, Prasad, Harber, & Shiffrar, 2005), deceptive intent (Sebanz & Shiffrar, 2009), vulnerability (Gunns, Johnston, & Hudson, 2002), age, and social dominance (Montepare & Zebrowitz-McArthur, 1988). Do observers with ASD have perceptual access to socially relevant motion cues? Observers with ASD might perceive visual motion accurately, but then fail to perform adequate social and cognitive analyses of that perceptual information. Conversely, observers with ASD might fail to perceive motion accurately, and as a result, social and cognitive analyses are rendered hopelessly futile. Resolution of this issue could have significant implications for the treatment of ASD.

Studies of the perceptual abilities of people with ASD have focused on the issue of local and global levels of visual analysis because observers with ASD tend to analyze visual images locally (for reviews, see Behrmann et al., 2006; Happé & Frith, 2006; Mottron et al., 2006). Because the visual perception of movement usually requires the global integration of information across space and time, numerous researchers have investigated visual sensitivity to coherent motion by observers with ASD. The results of these studies have been mixed, to say the least. Among studies in which visual sensitivity to coherent motion with RDKs is measured, some find significant deficits in observers with ASD (Atkinson, in press; Davis et al., 2006; Milne et al., 2002; Pellicano et al., 2005; Spencer et al., 2000), whereas others do not (de Jonge et al., 2007; Del Viva et al., 2006;

Milne et al., 2006). Similarly, among psychophysical studies in which PLDs of human motion are employed, some find significant deficits associated with ASD (Blake et al., 2003; Kaiser et al., 2008; Klin & Jones, 2008; Klin et al., 2003; Klin et al., 2009) and others do not (Hubert et al., 2007; Moore et al., 1997; Parron et al., 2008). Thus, neither the perception of RDKs nor point-light walkers by observers with ASD can be understood as simply reflecting some automatic default to local motion processes. Thankfully, recent findings provide avenues for a potential synthesis of these otherwise confusing data.

First, neural activity in area STS is strongly modulated by PLDs of human movement and weakly modulated by moving random dot displays (Dakin & Frith, 2005). Dysfunction in area STS is associated with ASD (e.g., Boddaert et al., 2004; Freitag et al., 2008; Herrington et al., 2007; Pelphrey, Morris, McCarthy, & LaBar, 2007; Waiter et al., 2004). This region is important for social cognition, and its dysfunction appears to be related to impairments in social cognition in ASD (Zilbovicius et al., 2006). If, as Dakin and Frith have suggested, activity in area STS is related to performance on tasks of visual motion perception, then deficits in STS activity may be associated with minor decrements in visual sensitivity to random dot displays and with substantial decrements in visual sensitivity to PLDs of human motion. If the functionality of area STS varies across individuals with ASD, then this might account for some of the variability across the studies summarized above. Research comparing STS activity across and within individuals performing well-controlled motion coherence tasks with RDKs and PLDs of human motion could test this proposal.

Second, motor ability correlates with visual sensitivity to coherent motion in random dot patterns in observers with ASD (Milne et al., 2006) and in observers with AS (Price et al., 2009); it correlates with visual sensitivity to PLDs of human motion in observers with ASD (Freitag et al., 2008) and in observers with AS (Price et al., 2009). Studies of perception–action coupling in typical observers and in nonautistic patients have demonstrated the existence of strong linkages between an observer's motoric abilities and that observer's visual sensitivity to motion (e.g., Bosbach, Cole, Prinz, & Knoblich, 2005; Jacobs & Shiffrar, 2005; Loula et al., 2005; Prinz, 1997; Viviani, 2002). Perception–action coupling is thought to play a particularly important role in social behavior (e.g., Knoblich & Sebanz, 2006). This raises the possibility that individual differences in motor system impairment, or perception–action coupling, may also contribute to visual sensitivity to movement and impairments of social behavior. Research investigating the relationships among motor ability, visual sensitivity, and social abilities is needed to address this issue.

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