Motion Perception in Autism: A "Complex" Issue

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Abstract

■ We present the first assessment of motion sensitivity for persons with autism and normal intelligence using motion patterns that require neural processing mechanisms of varying complexity. Compared to matched controls, our results demonstrate that the motion sensitivity of observers with autism is similar to that of nonautistic observers for different types of first-order (luminance-defined) motion stimuli, but significantly decreased for the same types of second-order (texture-defined) stimuli. The latter class of motion stimuli has been demonstrated to require additional neural computation to be processed adequately. This finding may reflect less efficient integrative functioning of the neural mechanisms that mediate visuoperceptual processing in autism. The contribution of this finding with regards to abnormal perceptual integration in autism, its effect on cognitive operations, and possible behavioral implications are discussed. ■

INTRODUCTION

Autism is a developmental disorder characterized by a triad of impairments affecting reciprocal social interactions, interpersonal communication, and imagination (Wing & Gould, 1979). A third area of abnormality concerns nontriadic or nonsocial impairments (Happé, 1999; Frith & Happé, 1994), grouped under the "Restricted repetitive and stereotyped patterns of behavior, interests, and activities" diagnostic description of autism in the DSM-IV (American Psychological Association, 1994). Non-triadic symptoms include abnormal preoccupations with parts of objects, islets of abilities, restricted repertoire of interests, and idiosyncratic responses to sensory stimulation. A significant proportion of these nontriadic symptoms implicates the visual–perceptual domain and can be described as either negative or positive. Negative symptoms can be defined as the absence of a typical behavior in response to visual information (e.g., absence of eye contact during interpersonal interaction). Conversely, positive symptoms are behaviors rarely or never evident in typically developing individuals (e.g., preoccupation with certain types of flickering or spinning objects).

Empirical evidence of abnormal visual processing in autism is currently available. For example, individuals with autism exhibit deficits in recognizing visually presented faces and facial emotions, possibly due to an atypical locally oriented processing (see Schultz, Romanski, & Tsatsanis, 1999, for a review). Recent functional neuroimaging studies have demonstrated that these deficits are associated with an abnormal localization of brain activation during face perception (Pierce, Müller, Ambrose, Allen, & Courchesne, 2001; Critchley et al., 2000; Schultz et al., 2000), suggesting that persons with autism develop alternative cognitive pathways for face and facial emotion recognition. However, the majority of the evidence demonstrating atypical visual processing in autism is related to an enhanced performance on visuospatial tasks implicating the detection or matching of simple geometric patterns among a more complex visual field. Accordingly, individuals with autism show an enhanced performance on the block design test (Shah & Frith, 1993), in reproducing impossible figures (Mottron, Belleville, & Ménard, 1999), and in discriminating elementary visual information, within a visual search paradigm (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). Another illustration of superior perceptual functioning has been demonstrated using the Embedded Figures Test (EFT) of the Wechsler intelligence test where autistic individuals are better at identifying a simple shape embedded in a more complex shape (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Using a functional neuroimaging technique, Ring et al. (1999) found different regions of cortical activation in participants with autism and a comparison group while performing an adapted version of the EFT. Based on the functional characteristics of the cortical areas activated for either group, these researchers concluded that the participants with autism were more dependent on perception than typically developing individuals and adopted a more "local" approach when performing the EFT.

This pattern of atypical performances has lead to the development of neurobehavioral theories of autism

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describing these anomalies as consequences of an abnormal multimodal structure of information in the visual modality. Common to these theories is the notion that persons with autism do not integrate visual information in an optimal manner. Rather, the visual processing of complex stationary objects and visual scenes seems to be characterized by an atypical bias towards local processing, or Weak Central Coherence (WCC; Frith, 1989), an absence of hierarchy in feature processing (Mottron & Belleville, 1993). Alternatively, this processing may occur through an enhancement in the detection of its of visual features (Enhanced Perceptual Functioning or EPF model; Mottron & Burack, 2001). WCC is believed to result in superior performance on tasks for which locally oriented processing is advantageous (i.e., EFT) but results in inferior performance when a holistic or global integration of visual features is necessary (i.e., face perception). Therefore, depending on the nature of the task, both the superior and inferior autistic performance on the aforementioned visuospatial tasks seem to be the result of a preference for local information processing. Furthermore, the differences in behavioral performance between autistic and control subjects seem to be associated to different underlying neural systems, suggesting that individuals with and without autism use different cognitive strategies when faced with the same task.

In the present study, a motion paradigm was used to evaluate the ability of autistic individuals to perceptually integrate visual information. The human motion pathway is hierarchical in structure and has relatively well-defined and well-documented levels of neural processing that are characterized by their capacity to process moving stimuli defined by different attributes. Therefore, measuring sensitivity to motion information processed at different levels along the visual pathway allowed for a direct assessment of motion perception capabilities in persons with autism, and also furthers our understanding on how these capabilities are related to the neural complexity of the visual motion information being processed.

Relatively few studies have investigated motion processing among persons with autism. Gepner, Mestre, Masson, and de Schonen (1995) found that the postural stability of children with autism, as measured by a force platform, was unaffected by the presentation of a radiating flow-field, suggesting that children with autism are less susceptible to visually induced movement relative to typically developing controls. These researchers concluded that the lack of postural reactivity might have resulted from either a motion perception impairment or from a lack of visual attention to the radiating stimulus. This finding is important, as it demonstrates an abnormal reaction to visually presented information in an empirical setting that approximates the true ecological setting. However, it is difficult to conclude from this experiment that reduced reactivity of the children with

autism results from a perceptual limitation, since higher order operations (e.g., attention) or motor functioning (e.g., inadequate sensorimotor integration) may also be implicated. More recently, a study investigating motion and form perception in autism demonstrated that participants with autism were less sensitive to global motion compared to typically developing controls (Spencer et al., 2000). However, no difference was found between the two groups on the form perception task. The selective decrease in motion sensitivity was interpreted by these authors as a specific deficit of dorsal stream functioning in autism, since global motion perception may be mediated by this system (Ungerleider & Mishkin, 1982; see Goodale & Milner, 1992; Merigan, Byrne, & Maunsell, 1991, for an alternative view). However, an alternative hypothesis can be forwarded based on the "complexity" of the motion information used in their experiment. Specifically, to discriminate the direction of global motion patterns, the visual system must first integrate local motion signals. If persons with autism adopt a more local approach at the expense of global information processing, the results of Spencer et al. (2000) may be at least partially explained by a deficit in integrating complex information at a perceptual level, regardless of the system implicated in its processing.

In the current article, we present a direct and systematic assessment of visual motion perception in persons with autism by using classes of moving stimuli. The motion sensitivity to translating, radiating, and rotating motion patterns was measured for observers with autism as well as for matched nonautistic observers. Each type of motion pattern was either of the first- (luminance-defined) or second-order (texture-defined) motion class (Cavanagh & Mather, 1989; Chubb & Sperling, 1988). These two classes of motion were used because a large body of psychophysical evidence has demonstrated that they are initially processed by two distinct neural motion mechanisms, varying in neural complexity (Bertone & Faubert, 1999; see also Clifford & Vaina, 1999, for a review) and are sensitive to subtle neural dysfunctioning of visual information processing (Bertone, Habak, & Faubert, 2000; Habak & Faubert, 2000). Contemporary motion models distinguish first- and second-order motion classes by the level at which they are processed along the motion pathway. First-order motion is initially processed by standard motion selective mechanisms operating in the primary visual cortex (or visual area V1). However, additional neural processing is required before second-order motion is perceived because standard motion analysis is unable to detect second-order information (e.g., Wilson, Ferrera, & Yo, 1992; Chubb & Sperling, 1988). For this reason, second-order motion can be considered a more "complex" motion class than first-order motion because it requires additional neural processing for integration. This is further evidenced by medical imaging data demonstrating initial first-order activation in area V1, whereas second-order motion

activation appears further along the motion pathway, namely in areas V3 and VP (Smith, Greenlee, Singh, Kraemer, & Henning, 1998).

RESULTS

Due to the different attributes that define the first- and second-order motion classes (e.g., luminance and texture modulation, respectively), comparing the mean differences of the absolute thresholds between the two motion classes is not informative. For this reason, the direction-identification threshold differences for the autistic and nonautistic observers of each type of motion (translational, radial, and rotational) were analyzed separately for the first- and second-order motion classes. The direction-identification thresholds were defined as the contrasts at which the direction of motion was correctly identified 75% of the time. For both the first- and second-order motion classes, the thresholds were expressed in terms of log motion sensitivity (Table 1).

First-Order Motion Class

Figure 1a shows the motion sensitivity for individuals with autism and the comparison group plotted as a function of motion type (translational, radial, and rotational). A two way ANOVA (Group × Motion Type) revealed no significant effect of group, $F(1,22) = 0.274$, $p = .6057$, demonstrating that persons with autism discriminated the direction of first-order motion as well as matched controls. A significant main effect of motion type, $F(2,44) = 3.996$, $p = .0254$, was found and a subsequent Tukey HSD analysis revealed that the direction of first-order radial motion was more difficult to discriminate relative to that of the translational and rotational motion types for both autistic and nonautistic observers. This finding may be a result of the perceived increase in speed of this type of motion, due to its apparent motion in depth (Bex & Makous, 1997). No
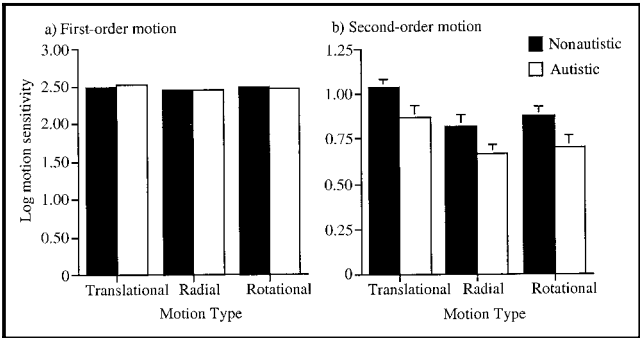
Figure 1. Mean direction-identification thresholds expressed in terms of log motion sensitivity for first- (a) and second-order (b) motion classes. Motion sensitivity was plotted as a function of motion type (translational, radial, and rotational) for both autistic (white bars) and nonautistic (black bars) observers for each motion class. Standard error bars are included. If not shown, then the standard error is smaller than the symbols used to represent it for any given motion condition. The graphs for the first- and second-order motion classes are presented on different scales.

significant Group × Motion Type interaction was found, $F(2,44) = 0.8721$, $p = .8721$, for this motion class.

Second-Order Motion Analysis

As shown in Figure 1b, the motion sensitivity of individuals with autism was significantly lower than that of the comparison group, $F(1,22) = 5.550$, $p = .0278$, across second-order motion types, demonstrating that persons with autism had more difficulty discriminating the direction of motion for the second-order motion patterns. As expected, a significant motion type effect was also found, $F(2,44) = 27.702$, $p = .000$. A Tukey HSD analysis revealed that both autistic and nonautistic observers were less sensitive to second-order radial ($p < .01$) or rotational motion ($p < .01$) relative to translational motion. This result is consistent with previous findings (Bertone et al., 2000; Bertone & Faubert, 1999). Finally, no significant Group × Motion type interaction was found, $F(2,44) = 0.131$, $p = .8778$, for this motion class.

Age Effects

No significant correlation ($p > .05$) was found for both the control and autistic observers between age and motion sensitivity for any of the motion conditions.

DISCUSSION

The present study used a motion discrimination paradigm to assess the ability of autistic individuals to perceptually integrate visual information. The findings revealed a dissociation in the sensitivity for two classes of motion necessitating different levels of neural processing. In addition, our results indicate that individuals with autism are less sensitive to second-order motion

Table 1. Mean Direction-Identification Thresholds Expressed in Terms of Log Motion Sensitivity (±SD) for Each Group and Motion Condition

	Motion Type		
Motion Class	Translational	Radial	Rotational
First-order			
Autistic	2.527 (0.039)	2.457 (0.112)	2.483 (0.079)
Nonautistic	2.502 (0.104)	2.444 (0.097)	2.488 (0.053)
Second-order			
Autistic	0.873 (0.230)	0.632 (0.175)	0.708 (0.213)
Nonautistic	1.046 (0.139)	0.799 (0.224)	0.848 (0.153)

than typically developing individuals. However, they are capable of discriminating first-order motion as well as the comparison group. The possible role played by neural complexity in this dissociation, its relation to abnormal visuoperceptual integration in autism and its effect on complex cognitive operations are discussed.

Motion Perception in Autism and Its Relation to Integrative Processing

Considering that an increased complexity of neural processing involved in the discrimination of motion direction is the unique factor that differentiates the first- and second-order motion perception, a selective decrease for second-order motion sensitivity is likely the result of less efficient integrative mechanisms operating at the visuoperceptual level. According to this interpretation, the specialized mechanisms able to specifically and efficiently process first-order motion patterns (Bex, Metha, & Makous, 1998; Morrone, Burr, & Vaina, 1998; Freeman & Harris, 1992; Regan & Beverly, 1978) are less affected by a limited capacity of neural integration than those mediating the processing of complex motion information, such as second-order class stimuli.

These results are relevant for explaining why individuals with autism are less sensitive to another type of ''complex'' motion, global motion (Spencer et al., 2000). Spencer et al. (2000) interpret their findings as an evidence for a specific deficit in dorsal stream functioning in autism, since motion selective cortical areas are traditionally associated with dorsal pathway (e.g., the medial temporal area). However, our results demonstrate that persons with autism are capable of discriminating the direction of the different types of first-order motion as well as matched controls. Consequently, individuals with autism do not have a visual motion processing deficiency per se, indicative of a decreased dorsal pathway functioning, since the first-order motion patterns used in the present study are processed by specialized ''hard-wired'' mechanisms located in this region. The fact that no specialized mechanisms are thought to exist for second-order motion (Badcock & Khuu, 2001; Bertone & Faubert, 1999) suggests that processing of any type of second-order pattern implicates a greater amount of neural circuitry and integrative processing for its direction to be discriminated. For this reason, we believe that our results are better explained by autistic observers' decreased capacity to integrate complex perceptual information rather than a specific inability to efficiently process motion information as such.

Integrative Inefficiencies in Autism: Possible Origin and Behavioral Manifestations

The dissociation in sensitivity among two classes of motion information that differ in the amount of neural computation involved in their respective processing supports the hypothesis of abnormal neural networks in autism. With the exception of abnormal neuronal oscillatory activity (Grice et al., 2001), previous support for this hypothesis in autism is speculative. For example, several authors have described how neural dysfunction in autism may originate from the hyperspecificity of neural representations (McClelland, 2000), excessive lateral synaptic inhibition (Gustafsson, 1997a, 1997b), and abnormal amounts of neural connectivity (Cohen, 1994). Other support for abnormal neural functioning in autism is even more indirect and is based on discarding the implication of subcortical mechanisms to the benefit of cortical regions in a particular deficit (Minshew, Goldstein, & Siegel, 1997). Regardless of the exact nature of this neural dysfunction, it is highly probable that the ability of an autistic person to process perceptual information would be compromised to a greater extent if the information is complex, since more neural circuits would be involved.

The current finding that autistic observers are selectively less sensitive to complex motion information highlights a limitation in neural functioning even within an elementary perceptual process. Accordingly, the direction-identification task used in the present study is cognitively simple, as the observers only have to choose between two possible motion directions after being presented with a moving stimulus. Although the amount of neural processing needed to correctly discriminate a motion direction is greater for the second-order motion stimuli, the cognitive load is maintained constant during the task. In this regard, this finding is in contrast with Minshew et al.'s (1997) proposition of intact early information processing in autism and impaired processing of ''higher level'' operations. Instead, it suggests that neural mechanisms mediating perceptual processing in autism may be implicated in this condition, therefore at an earlier stage than previously believed.

Associating inefficient neural functioning at a perceptual level to higher level cognitive deficits and atypical behaviors characterizing autism may be beyond the scope of this discussion. However, it is reasonable to hypothesize that at least some of the behavioral manifestations of autism are due to neural dysfunction that affect perceptual processing. An important function of perceptual systems is to provide the brain with accurate and meaningful internal representations of our external environment. Neural representations underlying our perception of events and subsequent association of these events with appropriate affect are necessary for higher level cognitive functioning to occur. If the construction of internal representations based on complex perceptual information is compromised in autism, it is possible that subsequent social behaviors necessitating the recognition of internal representations may be affected and manifested by characteristic ''negative'' autistic behaviors. Accordingly, the lack of involvement of young children with autism in reciprocal behavior implicating

the visual modality, such as the production and decoding of pointing behaviors (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997), gaze following (Leekam, Hunnisett, & Moore, 1998), and emotion and face recognition (Schultz et al., 2000) may originate from impaired perceptual information processing in autism.

Is the Limitation in Processing Complex Information Specific to the Visual Domain?

Our suggestion of inefficient integrative functioning of the neural mechanisms mediating visuoperceptual processing in autism is based on the assessment of a specific perceptual subsystem, namely, that which underlies visual motion perception. Consistent with this interpretation, a predisposition to local information processing has been shown for several other hierarchical tasks in autism in the visual domain (Rinehart, Bradshaw, Moss, Brereton, & Tonge, 2000; Mottron et al., 1999; Ring et al., 1999; Jolliffe & Baron-Cohen, 1997). Therefore, it seems that the perception of different types of complex visual information (e.g., visuospatial, motion, etc.) is compromised in autism. However, locally oriented information processing may also extend to hierarchical auditory information since it has been demonstrated that individuals with autism present an enhanced performance for processing elementary auditory stimuli (Mottron, Peretz, & Ménard, 2000). It is therefore possible that individuals with autism use the same processing ''strategy'' when faced with complex information originating within each of the perceptual subsystems.

The construction of meaningful internal representations is contingent on the efficient integration of information originating from each perceptual subsystem. Unimpaired temporal lobe functioning would therefore be primordial in the construction of such representations, since the temporal lobe has the important role of integrating complex perceptual information between modalities (Gloor, 1997). Recent brain imaging findings demonstrating temporal lobe dysfunction in the form of hypometabolism (Zilbovicius et al., 2000) and neural rededication during face perception (Pierce et al., 2001; Critchley et al., 2000; Schultz et al., 2000), suggesting that the temporal lobe functioning in autism is abnormal. If this is the case, integrative processing between each perceptual subsystem may also be compromised during complex perceptual processing in that neural signals originating from each of the primary cortices are not combined in an optimal manner. It is therefore possible that integrative mechanisms are less efficient both within a specific perceptual subsystem (i.e., as reflected by the present findings) as well as between subsystems in autism. This viewpoint is more ecologically viable since more than one perceptual attribute is involved in the construction of internal representations necessary for subsequent higher order functioning (Faubert & Bellefeuille, 2002). Furthermore, anecdotal accounts of autism often describe a fragmented perception of the world, which is not limited to one type of perceptual information but often implicates difficulties in integrating more than one type of perceptual attribute into a meaningful perception (Gerland, 1997).

Conclusion

The present study demonstrates that individuals with autism and normal intelligence process motion stimuli that require additional neural processing less efficiently than a comparison group, possibly due to less efficient integrative functioning of neural mechanisms at the perceptual level. In this context, we interpret the current findings not as a choice of a cognitive style that does not favor integrative information processing (Happé, 1999), but as a deficit that does not allow the autistic person to integrate information efficiently at a perceptual level and possibly at higher levels as well. Although this deficit may result in increased performance on tasks where local processing is advantageous (e.g., Mottron et al., 1999; Frith, 1989), the negative consequences of such a limitation may be manifested by the atypical cognitive performances in the visual modality in autism and more speculatively, by abnormal visually related autistic behavior.

METHODS

Participants

Twelve individuals with autism and normal intelligence (mean IQ = 100.8) were recruited from a specialized clinic for persons with autism. A diagnosis of autism was obtained using the algorithm of the Autism Diagnostic Interview (ADI) (Lord, Rutter, & Le Couteur, 1994) combined with the Autistic Diagnostic Observation Schedule General (ADOS-G) (Lord et al., 1989), both of which were conducted by a trained researcher (L. M.) who obtained reliability on these instruments. All participants with autism had a score above the ADI/ADOS cut-off in the four areas relevant for diagnosis (social, communication, restricted interest and repetitive behaviors, and age of symptom onset). Twelve typically developing participants were recruited from the community as a comparison group. These were screened for a past or current history of psychiatric, neurological, or other medical disorder and all had a typical academic background. The groups were matched as closely as possible in terms of laterality, gender, and chronological age. The mean age of the control and autism groups was 13.13 and 12.18 years, respectively. All participants had normal or corrected-to-normal vision and were naive to the purpose of the study.

Apparatus

The stimulus presentation and data collection were controlled by a Power Macintosh 6100/66 microcomputer

and presented on a 14-in. AppleVision color monitor refreshed at a rate of 67 cycles per second (Hz). The screen resolution was 640 × 480 pixels. The Pixx© graphics program controlled stimulus generation and animation. The luminance of the monitor was gamma-corrected to minimize the nonlinearities in the display. Gamma-correction was implemented with a color calibration within the Pixx© graphics program. Calibration and luminance readings were taken using a Minolta CS-100 Chroma Meter colorimeter.

Stimuli

All motion stimuli were presented to subjects within a circular region at the center of the display that had a diameter of 5° when viewed from a distance of 114 cm. The mean luminance of the remainder of the display during testing was 20.03 cd/m² ($u' = 0.1832$, $v' = 0.4608$ in Commission Internationale de l'Eclairage u' v' color space) where L_{min} and L_{max} were 0.07 and 40.01 cd/m², respectively.

The motion stimuli consisted of first- and second-order translating, radiating, and rotating patterns. The first-order motion stimuli (Figure 2a) were luminance-modulated noise patterns produced by adding static gray-scale noise to modulating sine waves of different profiles (e.g., a vertical sinusoid for translational motion, a radially symmetrical sinusoid for concentric motion and an angled sinusoid for rotational motion). The noise consisted of dots (1 × 1 pixel, measuring approximately 2.235 arc min) with individual luminances randomly

Figure 2. A schematic representation of the motion stimuli used in the present experiment: (a) luminance-defined or first-order translational, radial, and rotational motion stimuli; (b) same types of contrast-defined or second-order stimuli.

assigned as a function of sin (x), where (x) ranged from 0 to 2π. The contrast (luminance modulation depth) of the first-order patterns was varied to determine direction-identification thresholds by varying the amplitude of the modulating sine wave. The amplitude of the luminance modulation for the first-order patterns could be varied from 0.0 to 0.5 defined as:

luminance modulation depth

$$= (L_{max} - L_{min})/(L_{max} + L_{min})$$

where L_{max} and L_{min} refer to the average highest and lowest local luminances in the pattern. The first-order luminance modulation levels used in the constant stimuli presentations (0.04, 0.02, 0.01, 0.005, 0.0025, and 0.00125) were chosen based on pilot studies. The second-order stimuli (Figure 2b) were texture-modulated noise patterns produced by multiplying rather than summing the same modulating sine waves to the gray-scale noise (Ledgeway & Smith, 1994). The depth of the texture modulation (contrast modulation depth) was also varied to find direction-identification thresholds by varying the amplitude of the modulating sine wave. The amplitude of the sinusoid therefore defined the contrast of the pattern and could be varied within a range of 0.0 and 1.0 defined as:

contrast modulation depth

$$= (C_{max} - C_{min})/(C_{max} + C_{min})$$

where C_{max} and C_{min} are the maximum and minimum local contrasts in the pattern. Second-order contrast modulation levels used during the constant stimuli procedures were 1.0, 0.333, 0.143, 0.111, and 0.059. For the translating and radiating patterns, the spatial and temporal frequency of the modulation was identical, at least for points along their horizontal radius. Their spatial and drift frequencies were 1 cycle per degree (cpd) and 2 Hz, respectively. The angled modulation of the rotating pattern underwent eight cycles per 360°. Its angular velocity was $\pi/2$ rad/sec.

Procedure

Participants were tested individually in a dimly lit room. In all conditions, they viewed the display binocularly from a distance of 114 cm, and their head movements were minimized using a chin rest. The stimuli were presented for 750 msec. To simplify responding instructions, the experimental session was comprised of three blocks, each of which is defined by the type of motion stimuli presented (translational, radial, or rotational). Therefore, only one motion type (e.g., translational) from both the first- and second-order motion class was presented within each experimental block. Practice trials
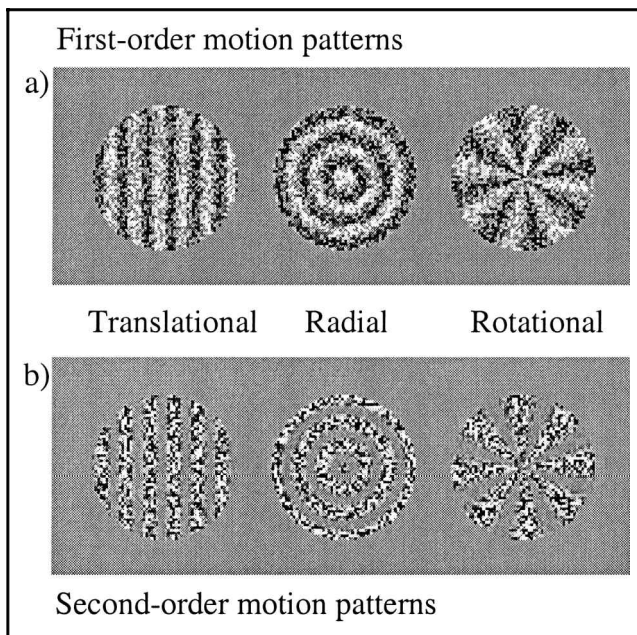
were completed before each block so that the participants could familiarize themselves with fixation, stimuli presentation, and responding.

Procedural instructions were given verbally to each participant prior to each experimental block. Participants were required to identify the motion direction (e.g., left vs. right, expanding vs. contracting, or clockwise vs. counterclockwise) of the stimuli by pressing one of two buttons on a keypad. During the experiment phase, the participants were reminded to fixate at the center of each pattern. The experimenter remained present throughout testing and initiated successive trials.

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