Perceptual Organization in Individuals with Autism Spectrum Disorder

Kris Evers

Ruth Van der Hallen

Ilse Noens

Johan Wagemans

University of Leuven

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Abstract

Autism spectrum disorder (ASD) is typically associated with problems in social communication and interaction, combined with restrictive and repetitive interests, behaviors, and activities. In addition, individuals with ASD often experience sensory abnormalities and have difficulties with perceptual organization, which can affect other aspects of information processing, such as attention, and perception of faces and motion. Researchers have studied atypical perceptual organization in individuals with ASD over the past decades, particularly in visual perception, finding both a reduced tendency to integrate information into meaningful wholes and a stronger focus on details in individuals with autism. This article reviews empirical findings and briefly describe two influential theoretical accounts, (*weak central coherence* and *enhanced perceptual functioning* theory), and more recent theoretical frameworks, which emphasize the imbalance between local and global processing, or anomalies at the level of the brain as an engine of prediction.

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by a combination of impairments in social interaction and communication, and repetitive, restricted interests, behaviors, or activities (1). Sensory abnormalities are prominent clinical features of ASD: More than 90% of children (2) and adults (3) with ASD experience hyper- or hyposensitivity. Those sensory symptoms persist across development and level of ability (2), but appear mostly in early childhood (4) for auditory, visual, olfactory, and tactile stimuli. Individuals with ASD have problems with perceptual organization and appear less sensitive to global motion (for a meta-analysis, see 5). Individuals with ASD also have difficulties integrating information across modalities, such as when they match auditory and visual emotional information (e.g., 6) or as seen in the attenuated McGurk effect (7). (In the McGurk illusion, a novel speech sound is perceived, when conflicting auditory and visual speech cues are presented.)

In this article, we review findings on sensory and perceptual processing—focusing on perceptual organization in ASD—and discuss novel theoretical frameworks. We review empirical findings demonstrating atypical perception organization in ASD and briefly describe two influential theoretical accounts, highlighting the variability within available empirical data and demonstrating how controlled experimental tasks and stimuli can help identify the nature of affected perceptual organization processes. We also elaborate on novel theoretical accounts and offer suggestions for research.

Atypical Perceptual Organization in ASD

Kanner (8) was the first to associate autism with a more locally oriented perceptual style, referring to an "inability to experience wholes without full attention to the constituent parts" (p. 246). However, not until the 1980s was the first empirical demonstration of poor perceptual organization published: Shah and Frith (9) showed that children with ASD could detect a target shape embedded in a larger figure more successfully than typically developing children. These findings spurred a permanent shift in the field: Researchers switched from an almost exclusive focus on behavior to investigating sensory and perceptual processing in individuals with ASD.

Two Theoretical Frameworks

Two influential theories on atypical perceptual organization in individuals with ASD have encouraged research on different aspects of local-global processing in ASD. The first is the weak central coherence theory (WCC; 10, 11). Individuals with ASD cannot grasp the global picture so they outperform typically developing individuals when preferential processing of local parts is advantageous for the task (as in the Embedded Figures Test; 9). More recent versions of WCC no longer describe atypical perceptual organization in ASD as an inability, but identify it as an atypical, more locally oriented preferential strategy. These versions also highlight the importance of evaluating distinct local and global processes independently (12).

A second theoretical framework, enhanced perceptual functioning (EPF; 13, 14), emphasizes the other side of the local-global coin. According to EPF, perception in ASD is characterized by superior local processing, which sometimes coincides with a diminished focus on global information. A more recent version of this framework ascribes an enhanced ability to detect predictable structures and links this to savant skills that occur in a few individuals with ASD (15).

Empirical Findings Reveal Much Variability

Early empirical findings in individuals with ASD are consistent with an inability to group local elements into coherent wholes and an increased focus on details. Compared to typically developing individuals, individuals with ASD are less sensitive to visual illusions, draw exceptionally well (i.e., providing many details), and are skilled in segmenting block design patterns (for a review, see 16). Similarly, in studies evaluating local-global processing in audition, individuals with ASD identified and discriminated isolated—hence local—auditory features such as pitch perception as accurately or more accurately than typically developing individuals. Furthermore, for those with ASD, global (e.g., semantic) information interfered less with local processing (for a review, see 17).

However, results are variable (for a review, see 16). A recent meta-analysis of 56 publications on perceptual organization in ASD (18) reported no evidence for increased processing of local information in individuals with ASD compared to typically developing controls across experimental tasks. In addition, those with ASD performed more slowly but as accurately on global tasks, especially when additional local information was also present, which suggests more local-to-global processing of information in individuals with ASD compared to global-to-local progression of information by typically developing individuals (18).

Taken together, these findings have led to two insights. First, scholars have realized that issues over how to define and measure local and global processing make it difficult to compare (and interpret) empirical findings. The research lacks clear guidelines on how to measure local and global processing. Two recent studies reported low correlations between performance on different local and global processing tasks (19, 20), questioning the validity of the different measures. Such results also suggest that local and global processing may be interdependent, which calls for a redefinition of local and global processing in relative terms (18).

Second, what was viewed as impaired processing is now understood as a difference in processing style. In other words, as a result of mixed and inconsistent findings, researchers have shifted from a processing impairment approach to the notion of an attenuated preference for global processing and an increased local bias in individuals with ASD. Such a change in perspective required a different method of evaluating perceptual organization in ASD: using implicit measures to reveal differences in preference rather than paradigms that target differences in (in)ability. Such implicit measures do not explicitly instruct participants to attend to the local or global level, so they indirectly assess individuals' local (or global) processing biases.

Few studies have evaluated local-global perception this way. In one (21), children with ASD accurately reported global characteristics of hierarchical letters when instructed to do so, but they were less inclined to mention these when asked what they had noticed first (their preference). Children responded similarly in two visual search tasks: a free-choice (preference) search task, in which participants were not directed toward a local or global target, but chose whatever target they noticed first, and an instructed visual search task, in which participants were explicitly instructed to search for a local (or global) target. Children with ASD performed less accurately on the free-choice search task, but not on the instructed, explicit task (22).

Modified multiple object tracking (MOT) tasks have provided another implicit measure of perceptual organization. A standard MOT task requires participants to track moving targets among distractors, a task children typically do well. In the modified version, instructions remained the same, but targets were grouped visually with distractors into more global structures (see Figure 1). Even though the global grouping cues were irrelevant for the task (participants were not instructed to attend to them), participants tracked local targets less accurately (see Figure 1; 23). However, the decline in performance was smaller in children with ASD than in typically developing children, suggesting that they were not as affected by the implicit grouping cues (see Figure 1; 23). This revealed a difference in processing style in individuals with ASD: They were less biased to process global-level information. However, in another study that used a slightly different version of the task (24), individuals with ASD and those without did not differ, possibly because of stronger (object-based) global grouping cues (24), which are difficult to ignore, even for those with ASD. Another factor that might explain the lack of difference on this measure between individuals with and without ASD is the proportionally larger number of grouped trials in the study (24), which might have induced an unwanted focus on global targets. Taken together, these inconsistent findings highlight the importance of specific stimulus and task characteristics, especially in relation to ASD.

[INSERT FIGURE 1 HERE]

Highly Controlled Tasks and Stimuli Allow Identifying (Un)Affected Processes

Researchers need to evaluate stimulus and task characteristics to identify which perceptual organization processes are affected. For this reason, vision scientists commonly administer basic, highly controlled experimental tasks using degraded stimuli. Gabor elements are often used because they match the properties of cells in early regions of the visual brain and constitute perfectly controllable stimuli (see Figure 2), in the sense that all their characteristics can be manipulated by the experimenter. Because of this controlled experimental environment, differences in performance between those with and without ASD can be attributed to the manipulated stimulus (or task) characteristics, of which the impact on specific perceptual organization processes is known.

We have used Gabor stimuli in visual search tasks (22) and in object identification tasks (25). In the latter, participants had to identify objects from dynamic arrays of Gabor patterns, which changed frame by frame from a random orientation into an organization along the contours of an object (see the right side of Figure 2). Children with ASD required more organized information to identify the object contours (in line with 26-28), suggesting that the interplay between local and global processes involved in identifying objects is disturbed in individuals with ASD.

[INSERT FIGURE 2 HERE]

Novel Theoretical Perspectives

Neither WCC nor EPF is grounded in a clear temporal or spatial neural model of perceptual organization, except in terms of broad networks of activation. This limits our ability to connect experimental findings with neural data, and makes it more difficult to empirically contrast or validate both theories. More recent theoretical frameworks are embedded more strongly in mechanistic theories on how the brain processes information.

For instance, the reverse hierarchy theory (29) describes a specific time course of global-to-local processing of visual information, and links this with structural distinctions in the brain. Incoming visual information is transferred immediately to higher areas of the brain by a fast and implicit process extracting the global information. If the task requires more detail, information is fed back to the lower areas of the visual brain for further processing. One view (30) is that these two processes are out of balance in individuals with ASD: Fast extraction of global gist is less efficient, but attention-driven processing of local elements is superior. This integrated framework unites WCC and EPF, and provides a mechanistic account at the neural level. An experimental evaluation of this framework calls for time-dependent measures, with either a strict manipulation of presentation time (e.g., 30) or an evaluation of the time course of the different processes involved (e.g., 25).

Other theoretical accounts have been inspired by predictive coding framework (31), which postulates that the human mind constantly generates predictions based on incoming information and previously learned associations. The complex nature of the environment and our own noisy biological system results in prediction errors—mismatches between one's predictions and the actual input. While some of those errors are relevant and should provoke an update of predictions, small violations of predictions are common and irrelevant in fluctuating or complex situations (e.g., social situations) and should be ignored. Therefore, individuals have to (meta-)learn what degree of violation of predictions to ignore to develop a more abstract level of representation.

Several researchers have argued that difficulties in generating or applying predictions are at the heart of symptoms of ASD (e.g., 32-34). These theories share a common cognitive mechanism with clear links to underlying neural processing, explaining most of the available data on the autism phenotype and information processing style. However, the authors disagree about the specific anomaly in the predictive coding mechanism. The more locally oriented information processing style or hyper- and hyposensitivity in individuals with ASD is considered one of many byproducts of difficulties with generating top-down predictions (32, 33) or distinguishing relevant from irrelevant prediction errors (34; for information on global motion perception problems, see 35). Because of these kind of problems at the level of the predictive brain, information processing relies more on actual concrete input, and does not progress to the typical high-order, more abstract, and thus more global level of information processing (for further discussion, see 32-34).

Looking Ahead

Sensory abnormalities and perceptual organization have been investigated intensively in research on ASD. Evidence suggests that individuals with ASD are slower to process global information, particularly when concurrent local information is present. Despite all the research, findings cannot be generalized across the entire autism spectrum because certain ASD subgroups are understudied. Therefore, researchers should incorporate females, individuals with an intellectual disability, and the elderly in studies on perceptual organization and sensory processing. Furthermore, the developmental trajectory of perceptual organization in ASD remains largely unknown because of the lack of longitudinal studies on local-global processing in ASD. Most research on perceptual organization targets visual processing, but research on audition shows similar results. While some scholars have considered hyper- and hyposensitivity a mere consequence of a more locally oriented processing style, the specific relationships between local and global processing and hyper- or hyposensitivity are understood less thoroughly, partly because of a lack of longitudinal research and partly because the coping strategies of children and their parents, and the level of scaffolding provided by the children's environment, are rarely considered in lab studies.

Promising novel accounts relate atypical perceptual processing to an imbalance between fast gist processing and slower extraction of details, or problems at the level of the anticipating brain. These new frameworks require further experimental validation to see if they will stand the test of time. Such testing should include both psychophysical and behavioral work, evaluating how individuals with ASD learn (un)predictable associations in their environments (see, e.g., 36) and studying their tolerance for uncertainty; these tests should also examine these problems at the level of the predictive brain (using brain imaging techniques). In addition, researchers need to examine links between experimentally measured differences in processing style and functioning in daily life. Such work could provide important insights into the perceptual skills children with ASD use to make sense of their surroundings.

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Correspondence concerning this article should be addressed to Kris Evers, Parenting and Special Education Research Unit, Leopold Vanderkelenstraat 32 (Box 3765), BE-3000 Leuven, Belgium; e-mail: kris.evers@kuleuven.be.

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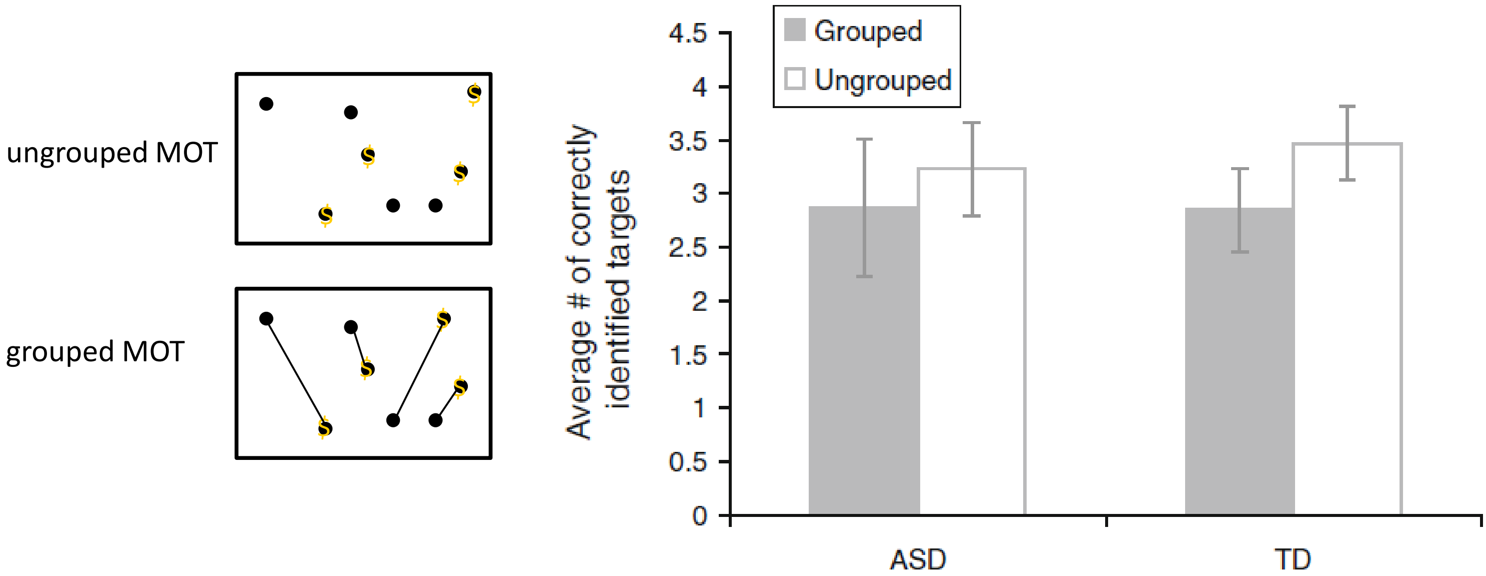

Figure 1. A modified multiple object tracking task (MOT) showed a reduced interfering effect of implicit global information in children with ASD compared to TD children. In the ungrouped MOT condition, participants are instructed to follow a set of targets, indicated with a $ sign, among moving distracters. In the grouped MOT condition, the task remains the same, but the targets and distracters are grouped visually. Both participant groups showed a significant decrease in tracking ability in the grouped condition compared with the ungrouped condition, demonstrating the impact of task-irrelevant grouping cues on further processing. However, this global interference effect was reduced in children with ASD. (Adapted from 23)

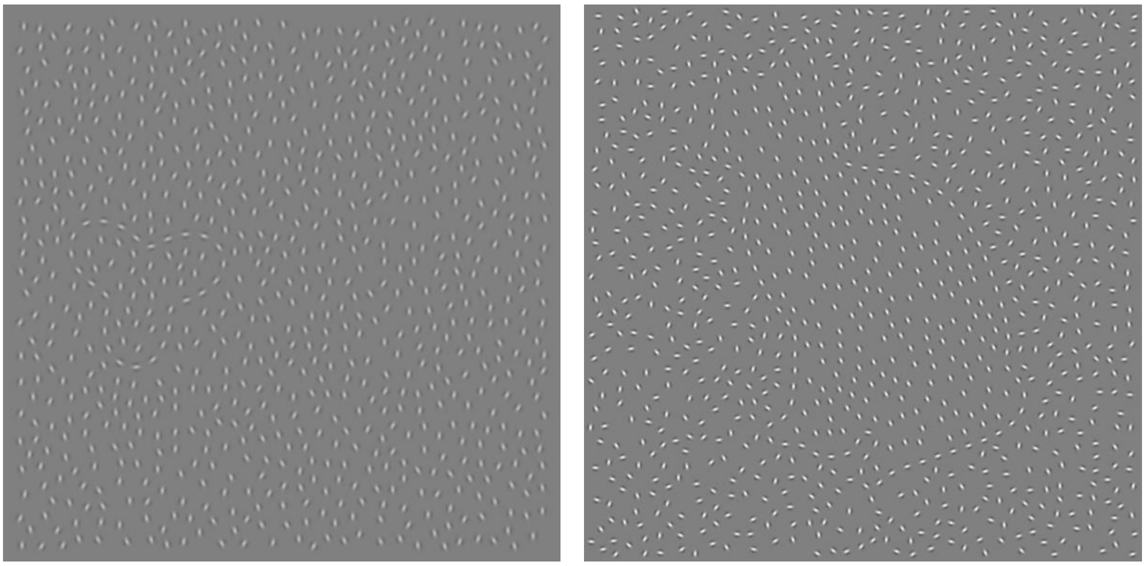

Figure 2. Gabor elements are highly controllable stimuli with properties that are attuned to cells in the early areas of the visual brain. Single Gabor elements can be combined to form anything from *meaningless* geometrical patterns (left figure, adapted from 22) to daily-life figures (a cat, right figure, adapted from 25).