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Typical Utilization of Gestalt Grouping Cues in Shape Perception by Persons with Autism Spectrum Disorder

Bat Sheva Hadad
Department of Special Education, Edmond J. Safra Brain Research Center, University of Haifa, Israel

Natalie Russo
Department of Psychology, Syracuse University, Syracuse, NY, USA

Ruth Kimchi
Department of Psychology, University of Haifa, Haifa, Israel

Vanessa Babineau
Department of Educational and Counselling Psychology, McGill University, Montreal, Canada

Jacob A. Burack
Department of Educational and Counselling Psychology, McGill University, Montreal, Canada

Abstract

The common finding of better locally oriented perception among persons with autism spectrum disorder (ASD) is based on evidence from paradigms in which hierarchical stimuli are used to pit local and global processes against one another. However, in most cases, determining whether group differences reflect reduced global processing, enhanced local processing, or both is difficult. To provide more conclusive evidence for global perception in ASD, we examined shape formation and sensitivity to Gestalt heuristics. Children with persons with ASD and mental age matched typically developing children completed tasks in which the organization of contour segments into a shape was likely to depend on utilizing cues of closure, spatial proximity, and collinearity. In Experiment 1, search efficiency was measured, with the efficiency of the global organization

Corresponding author:
Bat Sheva Hadad, University of Haifa, Mount Carmel, Haifa 30905, Israel.
Email: bhadad@univ.haifa.ac.il

indicated by the slope of the best-fitting linear reaction-time function over the number of presented items. In Experiment 2, contour integration task was administered, while Gestalt cues and the contour to background spacing ratio were manipulated independently. The findings indicated typical shape formation among the persons with ASD. Furthermore, certain interactive relations between Gestalt grouping cues that are known to govern shape formation in typically developing individuals determined the extraction of the global shape among the participants with ASD.

Keywords
shape formation, collinearity, closure, spatial proximity, global–local, contour integration, ASD

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The initial questions in the study of perceptual processing among persons with autism spectrum disorder (ASD) concerned whether the whole of a stimulus dominates or whether the parts are so salient that the whole becomes secondary. These questions were based on clinical observations that individuals with ASD were particularly attuned to local regularities in their environment. To contextualize these observations, experimental paradigms were designed to pit the perception of global configuration and that of local elements against one another, such as in embedded figures and hierarchical processing tasks. The evidence from these initial studies appeared to indicate an advantage for persons with ASD in selecting local elements and a concomitant deficit in the ability to integrate these local elements into a big picture. The findings from these and other related studies led initially to the formulation of the weak central coherence (WCC) account of ASD (Frith, 1989; Happé & Frith, 2006).

According to the original version of the WCC theory of ASD (Frith, 1989; Frith & Happé, 1994), persons with ASD were depicted as especially able to focus on details in the environment because they are unable to integrate information into a coherent whole. However, contrary to expectations based on WCC, persons with ASD did not show particular deficits in global processing, nor did they consistently show relative strengths in local, or detailed, processing either with the traditional hierarchical global–local stimuli or with other stimuli used to tap into related processes (e.g., Mottron, Burack, Stauder, & Robaey, 1999; Mottron et al., 1997; Ozonoff, Strayer, McMahon, & Filloux, 1994). In contradiction to the WCC's deficit approach to global attending and strength-based approach to local processing, these findings suggested that the differences in performance between persons with ASD and others might be due to style of processing rather than to actual differences in abilities at either level of processing. This point was highlighted by Plaisted, Swettenham, and Rees (1999) who found that persons with ASD with at least average intelligence showed lower levels of global processing on a divided attention task, in which the global and local processing were presented in competition with each other, but not on a selective attention task, in which global and local processing could be undertaken independently of the other. The findings of apparently intact global processing in the selective attention task were interpreted as further evidence against the WCC model, as Plaisted et al. suggested that the source of the lower level of global processing on the divided attention task is not one of ability or defect, but rather simply one of style, or bias, of processing. In this example, when either one or the other of the levels can be used, the de facto processing of typically developing (TD) persons seems to be the one in which global processing is prioritized, whereas for persons with ASD the default seems to be the local level of processing. Consistent with these findings, in a study of the influence of explicit versus implicit instructions on local–global visual processing, Van der Hallen et al. (2016) showed that when given explicit task instructions, persons with ASD performed equally well as compared to TD persons matched on chronological and mental age (MA).

In response to this body of empirical evidence, the notion of WCC has been reconceptualized (Happé, 1999; Happé & Frith, 2006) within a revised model in which weak coherence was considered as a characteristic rather than a cause of autistic behavior and as a bias rather than a deficit. Concurrent with this reconceptualization of WCC, Mottron and colleagues (Mottron & Burack, 2001; Mottron et al., 2006) proposed the EPF model in which persons with ASD display an enhanced ability to process the local elements of stimuli that can interfere with Gestalt processing at times.

Use of Gestalt Shapes to Assess WCC and EPF

The evidence in support of both the WCC and the EPF approaches emanates largely from paradigms using hierarchical stimuli, in which larger figures are constructed by suitable arrangement of smaller figures, as in the typical global–local paradigm (Navon, 1977). The global shape of such stimuli can be extracted from the relative position of the local elements, as the local elements in these stimuli are texture molecules (Kimchi, 1992) or placeholders (Pomerantz, 1983), or it can be based on analysis of low spatial frequencies (e.g., Badcock, Whitworth, Badcock, & Lovegrove, 1990; Dakin & Frith, 2005). Furthermore, such displays pit local and global processes against one another, thereby impeding the ability to determine whether group differences reflect reduced global processing, enhanced local processing, or both. To provide more conclusive evidence for global perception among persons with ASD, we examined shape formation and sensitivity to various Gestalt heuristics and their interactions in forming a global representation.

Testing the ability of individuals with ASD to utilize the Gestalt grouping cues governing typical perception (e.g., Hadad & Kimchi, 2006, 2008) may provide insights into how an organized representation is achieved in individuals with and without ASD, tapping qualitative difference in perceptual processing between these two groups. The initial evidence is mixed as groupings based on similarity (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Falter et al., 2010; Farran & Brosnan, 2011) or closure (Bölte et al., 2007; Brosnan, Scott, Fox, & Pye, 2004) have consistently been found to be less efficiently processed by persons with ASD, whereas the evidence with proximity-based groupings includes examples both of reduced sensitivity (Bölte et al., 2007; Brosnan et al., 2004) and of typical levels (Falter et al., 2010; Farran & Brosnan, 2011). Similarly, conflicting evidence is provided regarding the sensitivity of grouping to common-motion among persons with ASD (Evers et al., 2014; O'Hearn, Franconeri, Wright, Minshew, & Luna, 2013). The mixed picture may result from different tasks that tap into different kinds of perceptual grouping, including element clustering, which determines which elements belong together, and shape formation, which determines cluster boundaries. As these two different aspects of grouping differ in their underlying attentional demands and time course (Kimchi & Razpurker-Apfeld, 2004; Razpurker-Apfeld & Kimchi, 2007; Trick & Enns, 1997), any findings are likely to be task-dependent.

The notion that the discrepant evidence is task-dependent is supported by the finding that participants with ASD were able to organize the whole representation utilizing the grouping cues of closure, good continuation, similarity, and proximity when the task involved element clustering (Avraam, Binur, & Hadad, 2019). Both the participants with ASD and the TD participants underestimated spatial distances *within* elements composing a perceived group, but overestimated those *between* elements composing two different perceived groups. These findings are inconsistent with the claims of attenuated global processing among persons with ASD, although the spatial distortions exhibited in this implicit task do not necessarily involve shape formation. Furthermore, grouping was assessed with a distance judgment task in displays in which illusory distortions were inherent in configurations exemplifying a specific Gestalt principle, rather than their possible interactive relations. Thus, the question of whether individuals with ASD are able to interactively utilize various Gestalt cues in shape formation, as is often the case in most natural visual scenes, remains unanswered.

The Present Study

In this study, we examined shape formation and its sensitivity to Gestalt heuristics among a group of children and adolescents with ASD and a group of MA-matched TD participants using stimuli in which shape formation likely depends on the utilization of the grouping cues of closure, spatial proximity, and collinearity. In Experiment 1, the participants were told to search as quickly and accurately as possible for a concave target among a variable number of convex distractors. The basic stimuli were composed of two unconnected line segments (see Figures 1 and 3) that were the same for the concave and convex stimuli, but with a different placement relative to each other, bending inward for the concave stimuli and outward for the convex ones. Accordingly, a focus on local components would not match task demands, as the discrimination between target and distractors required grouping of the contour segments into coherent two-dimensional shapes. Search rate, defined by the slope of the best-fitting linear reaction time (RT) function over the number of items in the display (e.g., Duncan & Humphreys, 1989; Treisman & Gormican, 1988), indicated the efficiency with which the target's shape was searched, with an efficient search indicating an organization of the contour segments into a coherent shape.

In Experiment 2, we administered a contour integration task in which a new group of participants was instructed to integrate contour-inducing elements into a contour that was segregated from background noise based on Gestalt heuristics. The strength of integration was studied by examining the effect of spatial properties of the elements on the amount of noise tolerated while detecting the target. Specifically, cues of closure, collinearity, and spatial proximity, and the ratio of contour and background spacing (Δ) were manipulated independently to examine the effects of signal (contour strength) versus those of the signal-to-noise ratio on integration.

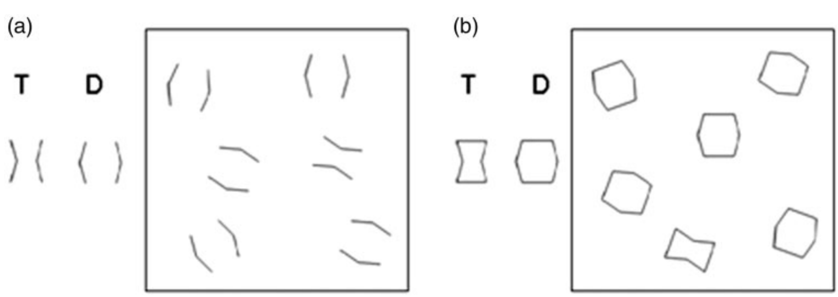

Figure 1. The target (T) and distractors (D) for the open and the closed stimuli presented in Experiment 1a. The examples illustrate a display size of 6. Reproduced from Hadad and Kimchi (2006).

Experiment 1: Visual Search

In Experiment 1a, we compared the ability of the participants with ASD and their MA-matched TD peers to utilize closure in shape perception. The participants were instructed to indicate whether a predefined target (i.e., a spindle-like concave shape) was present among a variable number of barrel-like (convex) shapes that were either open or fully closed (Figure 1). Search efficiency was indicated by search rate, defined by the slope of the best-fitting linear RT function over the number of items in the display. Generally, search is considered efficient and effortless if the time taken to detect a target is independent of the number of items in the display, but considered effortful if the time taken to detect the target increases with the number of items in the display (e.g., Duncan & Humphreys, 1989; Treisman & Gormican, 1988). In studies of the critical effect of closure in shape formation, search is found to be fast and efficient for the closed stimuli but slow and inefficient for the open ones among both TD adults (Elder & Zucker, 1993; Hadad & Kimchi, 2006, 2008), and young children (Hadad & Kimchi, 2006).

In natural scenes, closed connected contours often appear in the image as fragmented, as a result of occlusion, shadows, or low-reflectance contrast. To group the image fragments projected on the retina and to form a shape, the perceptual system must utilize the interactive effects of closure with other perceptual organizational cues. Specifically, the perceptual system has been shown to use collinearity, when available, to enhance closure for the perceptual grouping of shape. This efficient computation of collinearity between elements becomes sensitive to regularities that match the statistics of real object contours over the years, reaching maturity during middle childhood (Hadad & Kimchi, 2006, 2008; Hadad, Maurer, & Lewis, 2010).

In Experiment 1b, we examined whether person with ASD use such a mechanism by utilizing the interactive computations between different grouping cues often involved in shape formation. Specifically, we tested the ability to spatially integrate closure-inducing fragments into a shape across variations in collinearity and the spatial proximity among their elements.

Method of Experiment 1a

Participants

The participants were 12 children diagnosed with ASD with normal cognitive abilities and 16 TD children (see Table 1 for participant characteristics).[1] The children with ASD were recruited from private schools for children with ASD and for children with special needs in

Table 1. Sample Characteristics for Children With HFA and TD Children in Experiment 1.

	ASD ($n = 12$) *M* (*SD*)	TD ($n = 16$) *M* (*SD*)
Chronological age	14.5 (4.1)	10.17 (1.9)
Nonverbal mental age	10.7 (2.9)	9.5 (1.1)[a]
Sex—male %	100	50

ASD = autism spectrum disorder; TD = typically developing.
[a]No significant difference between groups in nonverbal mental age, $t(26) = 1.86$, $p > .1$, and in chronological age, $t(26) = 1.76$, $p > .1$.

the Montreal area, via a recruitment letter sent home to the parents. The TD children were recruited through an advertisement placed in a monthly local newspaper for parents. All of the participants had normal or corrected-to-normal vision. The procedure was approved by the Human Research Ethics Committee at McGill University. Informed consent was obtained from the parents.

The diagnoses for the participants with ASD were based on school records of diagnoses by a developmental pediatrician or pediatric neurologist based on DSM-IV criteria for Autistic Disorder (American Psychiatric Association, 1994) and confirmation by psychologists in the educational institutions. At the time of the testing, none of the participants showed signs of gross neurological or medical abnormalities, and none had known histories of psychiatric disorder or motor or visual impairment.

The participants with ASD were assessed for intelligence level to ensure a nonverbal MA above 8 years according to the Leiter International Performance Scale-Revised (Leiter-R; Roid & Miller, 1997). Composite brief IQ subtests were administered and scored according to the manual. The four subtests of the Brief IQ include of Sequential Order, Repeated Patterns, Picture Concepts, and Form Completion. All of the subtests on the Leiter-R involve game-like tasks presented with an easel and cards and require neither verbal instructions nor verbal responses.

Apparatus and Stimuli

Display presentation and data collection were controlled by a Dell GX-270 PC portable computer. The participants responded by pressing on computer keyboard keys. A full description of the stimuli and procedure is presented by Hadad and Kimchi (2006). Briefly, the basic stimuli were composed of two unconnected bent lines of equal size, spatially arranged to form a concave, spindle-like shape (the two lines bending inward) and a convex, barrel-like shape (the two lines bending outward). The target and distractor configurations for the open and closed conditions are depicted in Figure 1. In the open condition, the target (the concave shape) and the distractors (the convex shapes) were composed of just the two unconnected lines. In the closed condition, the target and the distractors were closed shapes formed by adding two identical connecting lines at the top and bottom of each of the open figures. The length of the top and bottom connecting lines was identical for the target and the distractors. The stimuli were randomly presented in one of 36 possible orientations. At a viewing distance of 70 cm, each configuration subtended 1.88° in height and 1.47° in width (width refers to the distance between the end points of the bent lines). Contour length was identical for the convex and the concave shapes. The distance between the convex inflection points (the convex shape) subtended 1.88°, and the distance between the concave inflection points (the concave shape) subtended 0.98°. Display sizes of 2, 6, or 10 items were used to examine search efficiency. The items were presented in jittered random locations in a 5×4 matrix subtending $15.95° \times 12.88°$.

Design and Procedure

The participants were instructed to detect the presence or absence of a spindle-like (concave) shape among a variable number of barrel-like (convex) shapes. The experiment involved an orthogonal combination of stimulus (open or closed), trial type (target present or absent), display size (2, 6, or 10), and group (ASD, TD). Stimulus, trial type, and display size were all manipulated within subjects. Stimulus was manipulated in two separate experimental blocks, the order of which was counterbalanced across subjects, and trial type and display size were randomized within block, with each combination occurring on an equal number of trials. Each of the experimental blocks was comprised of 72 trials, preceded by a practice block of 24 trials. Feedback was provided during the practice block to ensure that all of the participants understood the task. Each experimental block was divided into six subblocks of 12 trials. Each trial started with a central fixation cross presented for 500 milliseconds. Following a 500-millisecond interval, the target display appeared and remained present until a response was elicited or 7 seconds had elapsed.

Results and Discussion of Experiment 1a

The mean RTs as a function of display size and stimulus on target-present and target-absent trials for the two groups are presented in Table 2. A mixed design analysis of variance (ANOVA; Group × Stimulus × Trial type × Display size) conducted on the error rates (ER) data did not reveal any significant effects, and thus, all the summaries and analyses of RT were based on the participants' mean RTs for correct responses.

The main analysis was based on two RT measures: (a) baseline RT (RT for a display size of 2), conventionally considered to measure response speed independently of search rate, and (b) the slope of the best-fitting linear function relating RT to display size, conventionally considered to measure search efficiency (i.e., the slopes of the resulting RT × Display size functions indicate the increasing rates in RTs per item [ms/item]). The ratio between target-absent and target-present slopes was greater than 2:1 for the TD group, as often demonstrated in visual search studies for search efficiencies (slope sizes; e.g., Wolfe, 1998), and slightly smaller (1.9:1) for the ASD participants. These RTs slopes were analyzed by a mixed-design ANOVA as well as by Bayes Factors, B, for the relevant tests with one degree of freedom (Morey, Romeijn, & Rouder, 2016). Values of B above 3 indicate *substantial evidence* for H1 over H0, and values of B below 1/3 indicate substantial evidence for H0 over H1 (Jeffreys, 1939).

RT analyses were carried out only on target-present data because only target-present trials require a discrimination of the target from the distractors, whereas target-absent slopes provide less reliable measures of search efficiency due to the different criteria used for deciding target absence (Chun & Wolfe, 1996). Mean baseline RTs and RT slopes for target-present trials are depicted in Figure 2 as a function of group and stimulus.

A mixed design ANOVA (Group × Stimulus) conducted on baseline RTs (Figure 2(a)) revealed faster responses to closed stimuli (995 ms) as compared to open ones (1,232 ms); $F(1, 26) = 20.96$, $p < .0001$, $\eta_p^2 = .48$. This difference did not vary between groups, $F(1, 26) = 1.21$, $p > .281$, suggesting no differences between the two groups in target–distractor discriminability for the different stimuli.

Table 2. Mean Reaction Times (RTs, in Milliseconds) on Target-Present and Target-Absent Trials in Experiment 1a.

Target absent							Target present					
	Open			Closed			Open			Closed		
Set size	2	6	10	2	6	10	2	6	10	2	6	10
ASD	1,044	1,287	1,534	767	821	870	1,016	969	1,117	807	826	799
TD	1,213	1,425	1,934	1,020	968	945	1,035	1,196	1,240	915	926	927

ASD = autism spectrum disorder; TD = typically developing.

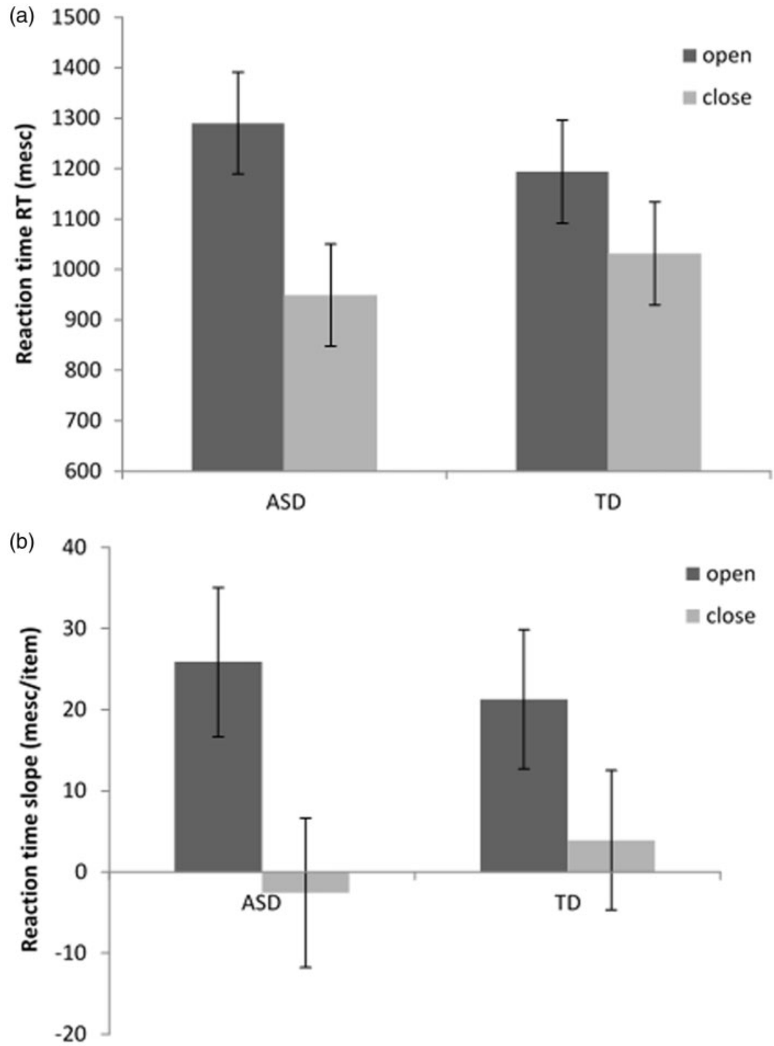

Figure 2. Search results for target-present trials in Experiment 1a: (a) Mean baseline reaction times and (b) search slopes, for open and closed stimuli for the two groups. Bars indicate 95% within-subject confidence intervals. ASD = autism spectrum disorder; TD = typically developing. *Note:* Please refer to the online version of the article to view the figures in colour.

The central analysis concerned the RT slopes (Figure 2b) as an index of search efficiency and revealed a significant effect of stimulus, $F(1,\ 26) = 11.90$, $p < .0002$, $\eta_p^2 = .33$. The RT slopes for the closed stimuli were shallow (-2 and 3 ms/item and did not differ from zero, $t < 1$, for the ASD and the TD groups), with similarly efficient search demonstrated by the two groups, $F(1,\ 26) = .49$, $p > .752$. The RT slopes for the open stimuli were considerably steeper, indicating an inefficient search (25 and 21 ms/item, for the ASD and the TD groups, respectively). The interaction between stimulus and group did not reach significance, $F(1,\ 26) = .89$, $p > .652$, indicating that for both groups, search efficiency for a concave target among convex distractors was high for closed stimuli but inefficient for open stimuli. Bayes factor calculated on search slopes $B_{H[0,\ 8.86]} = .31$ confirmed this null effect of group and

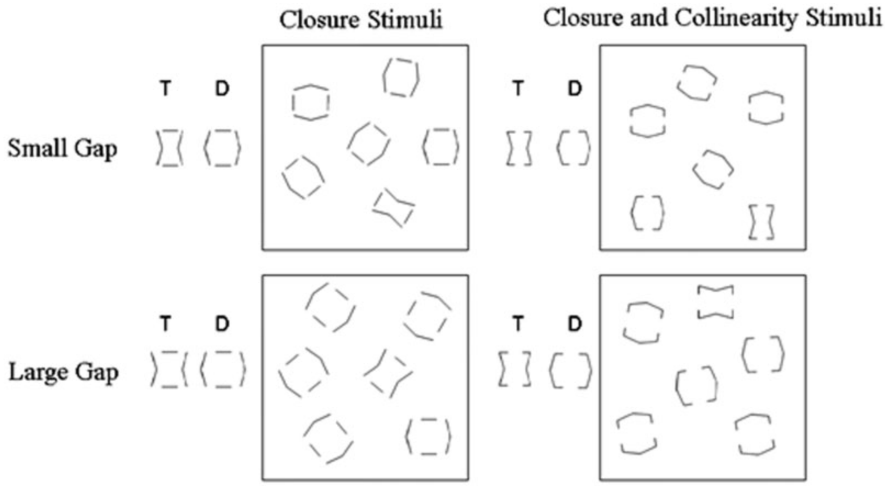

Figure 3. The target (T) and distractors (D) for each combination of stimulus (closure or closure and collinearity) and gap (small or large) presented in Experiment 1b. The examples illustrate a display size of 6. Reproduced from Hadad and Kimchi (2006).

provided evidence for the findings of no difference in the role of closure in spatial integration between the two groups.

These findings suggest that closure plays a similar role in shape perception for persons with ASD as for TD persons. The members of both groups are able to derive the shape of a closed figure but encountered difficulty without closure. In the absence of closure (i.e., the open stimuli), the discrimination between the concave and the convex stimuli cannot be based on shape properties, but rather requires an explicit apprehending of the relative spatial placement of the two line segments for each stimulus. Thus, the similar pattern of search for the open stimuli demonstrated by the two groups further implies typical visual spatial abilities among persons with ASD (e.g., Caron, Mottron, Rainville, & Chouinard, 2004).

Based on the findings that the participants with ASD were as able as the TD participants to derive the shape of a closed, connected figure, we next examined their ability to utilize groupings in displays in which, as in most natural settings, shape formation involved interactive effects among different grouping cues. Specifically, we tested their ability to utilize closure in fragmented figures as a function of the spatial proximity between the closure-inducing fragments and the presence or absence of collinearity.

Experiment 1b

In this experiment, we used the same visual search task as in Experiment 1a, with the same spindle-like (concave) shapes as targets and barrel-like (convex) shapes as distractors. However, the closed connected concave and convex shapes were adapted to form two types of fragmented stimuli. The target and distractors were now disconnected line configurations in which the spatial proximity between the line segments varied and, depending on the location of the gaps, either closure alone or closure and collinearity were present (see Figure 3).

On the basis of previous work with TD individuals on visual search (Hadad & Kimchi, 2006), primed-matching (Hadad & Kimchi, 2008; Kimchi, 2000), and contour integration (Hadad et al., 2010) tasks, we expected a differential effect of spatial proximity on search rate for the two types of stimuli. Target search was expected to be efficient for both the closure and the closure-and-collinearity stimuli when the closure-inducing line segments were spatially close, but only for the closure-and-collinearity stimuli when the closure-inducing lines were spatially distant. However, the critical question was whether shape formation in ASD and its sensitivity to Gestalt heuristics differs from that of TD individuals. Thus, search efficiency was tested as a function of stimulus (closure vs. closure and collinearity) and spatial proximity (small vs. large gap). If persons with ASD utilize Gestalt cues in a manner characterizing shape formation among TD persons, an interactive effect of stimulus and proximity on search efficiency of the fragmented target would be obtained, as described earlier. Such a pattern would demonstrate typical shape formation, extending the conclusions about typical perceptual organization in persons with ASD, beyond that involved in processing global properties and the perception of the hierarchical structure.

Method of Experiment 1b

Participants

The participants were the same two groups who participated in Experiment 1a.

Stimuli

The closed connected concave and convex shapes used in Experiment 1a were adapted to form two types of fragmented stimuli. The closure stimuli were generated by removing the end portions in each of the top and bottom connecting lines, yielding a fragmented figure with four gaps. The closure-and-collinearity stimuli were generated by removing the central portion in each of two connecting lines so that the remaining portions of each connecting line were collinear, yielding a fragmented figure with two gaps. The line segments were either spatially close (small gap condition) or spatially distant (large gap condition). For each stimulus type—closure and closure-and-collinearity stimuli—the size of the line segments was kept the same in the two gap conditions. The total gap size was the same for the closure and the closure-and-collinearity stimuli for each gap condition. The target and distractor configurations for the four combinations of stimulus and gap are presented in Figure 3. At a viewing distance of 70 cm, the stimuli subtended 1.88° 1.47° and 1.88° 1.97° for the small-gap and the large-gap conditions, respectively. The gaps between the lines in the closure stimuli subtended 0.24° each in the small gap condition and 0.49° each in the large gap condition. The gaps in the closure-and-collinearity stimuli subtended 0.48° each in the small gap condition and 0.98° each in the large gap condition. Display sizes of 2, 6, or 10 items were used. The items were presented in jittered random locations in a 5×4 matrix subtending $15.95° \times 12.88°$.

Design and Procedure

We used an orthogonal combination of the five factors of group (ASD/TD), gap (small or large), stimulus (closure or closure and collinearity), trial type (target present or absent), and display size (2, 6, or 10). Group was a between-subjects factor and the other factors were manipulated within subject. The four combinations of gap and stimulus were administrated in four separate blocks with the order of blocks determined by a Latin Square. Trial type and display size were randomized within block, with each combination occurring on an equal number of trials. Each of the experimental blocks included 72 trials, which were preceded by 24 practice trials. All of the other aspects of the design and procedure were the same as those in Experiment 1a.

Results and Discussion of Experiment 1b

The mean RTs for the two groups as a function of display size, stimulus, and gap size for target-present and target-absent trials are presented in Table 3. A mixed design ANOVA (Group × Gap × Stimulus × Trial type × Display size) conducted on the ER data showed that the participants were generally more accurate when the line segments were spatially close (mean ER = 10%) than when they were spatially distant (mean ER = 13%), $F(1, 26) = 4.49$, $p < .042$. No interactions involving group were found for ER data, and thus the main analysis was based on mean RTs for correct responses. The mean baseline RTs and RT slopes for target-present trials are shown in Figure 4 as a function of group, gap, and stimulus. Again, we focused on target-present data, for the reasons cited in Experiment 1a.

Baseline RTs

A mixed design ANOVA (Group × Gap × Stimulus) conducted on the baseline RTs (Figure 4(a)) revealed no significant difference in RT between the groups, $F(1, 26) = 0.65$, $p > .432$, nor any effect of gap, stimulus, $F(1, 26) = 0.29$, $p > .593$, or their interaction, $F(1, 26) = 0.17$, $p > .687$, suggesting no group difference in target–distractor discriminability for the different stimuli.

RT Slopes

The analysis revealed a significant interaction between stimulus and gap on search rates, $F(1, 26) = 9.59$, $p < .004$, $\eta_p^2 = .28$, but no significant interaction among stimulus, gap, and group, $F(1, 26) = 0.89$, $p > .356$. A Bayes Factor calculated on search slopes $B_{H[0,\ 16.96]} = .32$ confirmed this null effect of the three-way interaction, providing evidence that the perceptual organization and grouping processes of persons with ASD are governed by the same interactive relations of spatial proximity and collinearity displayed by their TD peers.

As evident in Figure 4(b), the gap between the line segments had a similar effect on both groups for both the closure stimuli and the closure-and-collinearity stimuli. Specifically, for

Table 3. Mean Reaction Times (RTs, in Milliseconds) on Target-Present and Target-Absent Trials in Experiment 1b.

	Target absent				Target present			
	Closure large	Closure small	Collinearity large	Collinearity small	Closure large	Closure small	Collinearity large	Collinearity small
TD								
2	990	893	883	886	873	843	884	882
6	1,119	929	1,005	949	898	839	876	821
10	1,164	974	946	973	922	865	886	932
ASD								
2	949	908	1,008	1,084	826	743	814	942
6	1,182	869	908	926	1,034	741	934	879
10	1,386	958	1,091	1,140	1,152	786	872	912

ASD = autism spectrum disorder; TD = typically developing.

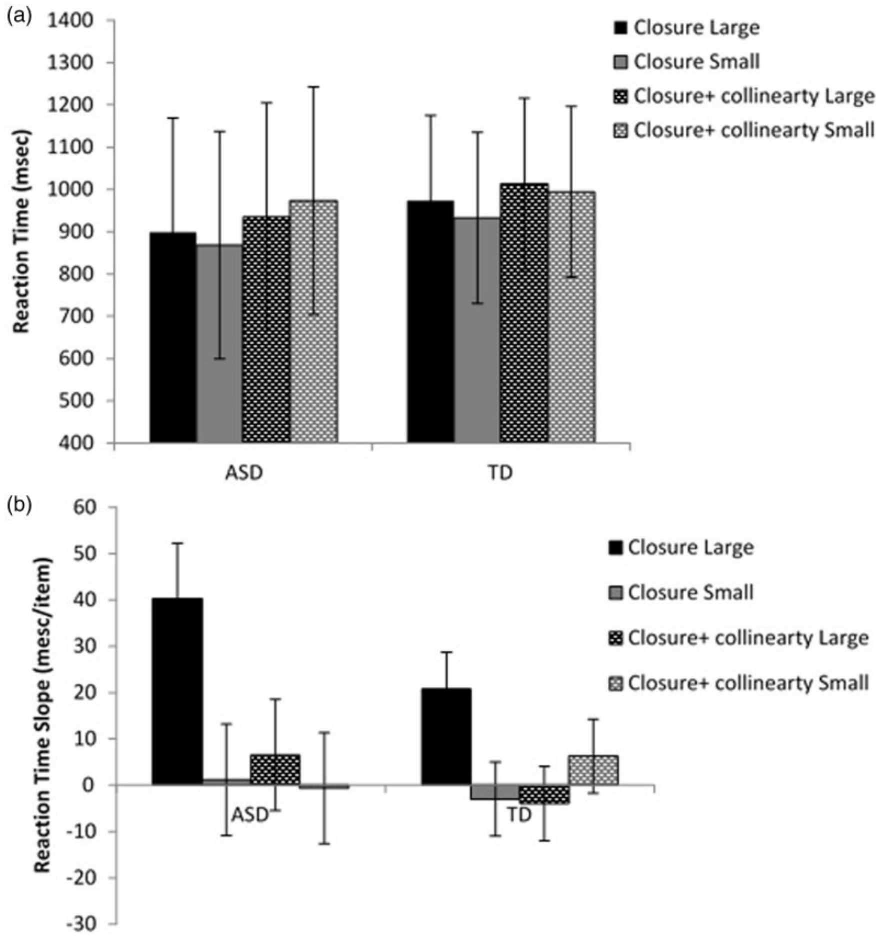

Figure 4. Search results for target-present trials in Experiment 1b: (a) Mean baseline reaction times and (b) search slopes for four combinations of stimulus (closure alone vs. closure + collinearity) and gap (large vs. small gap). Bars indicate 95% confidence intervals. ASD = autism spectrum disorder; TD = typically developing. *Note:* Please refer to the online version of the article to view the figures in colour.

the *closure stimuli*, search rate varied with gap between the line segments, $F(1, 26) = 10.05$, $p < .004$. $\eta_p^2 = .29$. Although marginally significant differences in search rates were found between the two groups, $F(1, 26) = 3.43$, $p < .071$, the effect of gap did not differ between groups, $F(1, 26) = 1.88$, $p > .182$. As expected, the TD participants exhibited shallow RT slopes when the line segments were spatially close (−3 ms/item) but steeper RT slopes when these line segments were relatively distant (20 ms/item). A similar pattern was observed for the ASD group, with shallow RT slopes when the line segments were spatially close (1 ms/item), but considerably steeper RT slopes when these line segments were relatively distant (40 ms/item).

In contrast, for the *closure-and-collinearity* stimuli, no significant effect of gap was observed, $F(1, 26) = .89$, $p > .562$, with both small and large distant line segments searched in an efficient way. Search rates were comparable between the groups, $F(1, 26) = 1.47$, $p > .245$, with both the participants with ASD and the TD participants exhibiting shallow slopes regardless of gap (0 and 6 ms/item for small gap, and 6 and −3 ms/item for large gap, for the ASD and the TD groups, respectively).

The findings for both groups indicated that the effect of spatial proximity between the closure-inducing line segments on search performance depended on whether closure alone or closure and collinearity were available. With closure alone, the search for the shape of spatially close line segments was highly efficient, whereas the search for the shape of spatially distant line segments was inefficient. When both closure and collinearity were available, the searches for the shape of both spatially close and spatially distant line segments were efficient.

These findings suggest that individuals with ASD, like MA-matched TD persons, can utilize closure for the perceptual grouping of shape when the closure-inducing line segments are spatially close. Individuals in both groups appear to be able to use collinearity to enhance closure when the closure-inducing line segments are spatially distant.

The findings that the search in the small gap conditions for both the closure and the closure-and-collinearity stimuli was as efficient as search for the closed connected stimuli in Experiment 1a for both groups suggests that shape formation of the disconnected line segments is as efficient as shape formation for connected closed line configurations when strong Gestalt cues are present. The findings indicate that this is the case both for persons with ASD and for TD persons, thereby further supporting the conclusion of typical perceptual organization processes underlying shape formation among persons with ASD.

The notion that low spatial frequencies play a role in the extraction of global structure, which has been suggested as a possible explanation for the global advantage observed with Navon's hierarchical stimuli (e.g., Badcock et al., 1990; LaGasse, 1993), cannot account for the typical shape formation found with the stimuli used here low-level mechanism is unlikely to show sensitivity to the particular interactive effects of collinearity and spatial proximity observed in the performance of ASD and TD participants. Rather, the present results suggest that persons with ASD can utilize the grouping cues of closure, proximity, and collinearity in the formation of a shape, as efficiently as TD persons. To strengthen our conclusions about the typical utilization of grouping cues in persons with ASD, the next experiment employed a contour integration task, similar to the one developed by Field, Hayes, and Hess (1993), in which detecting an embedded contour cannot be solved by lower spatial frequencies channels and requires global linking of elements across space (Dakin & Frith, 2005).

Experiment 2: Contour Integration

The utilization of the same Gestalt cues was tested with a new group of participants using a contour integration task. The participants detected *enclosing* "()" and *open* ")(" arc configurations formed from target Gabors in a background of randomly oriented and positioned noise Gabors (Figure 5). The effects of spatial proximity and collinearity for the open and the closed configurations were studied by contrasting four combinations of these factors that allowed their independent and interactive effects to be examined while controlling for the relative spacing of elements in the target and background (delta; Δ).

Participants

Eighteen adults with ASD (mean age: 23.73, range: 21–30) and 18 TD adults (mean age: 25.67, range: 19–27) with similar IQ scores (means: 107.73 for the ASD and 115.5 for the TD group) participated in this set of experiments.[2] The ASD diagnoses were confirmed by previous diagnoses based on the Autism Diagnostic Observation Schedule-Generic (ADOS-G; DiLavore, Lord, & Rutter, 1995). The participants also completed the

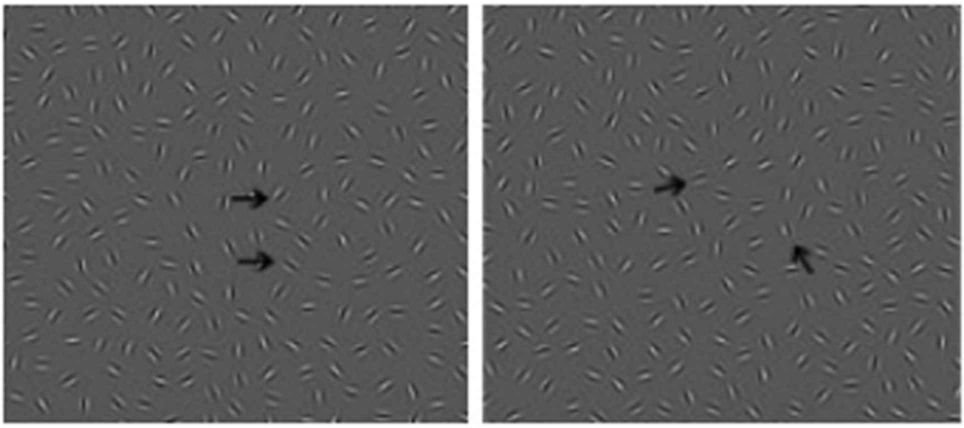

Figure 5. Examples of contour displays used in Experiment 2. Enclosing (a) and open (b) arc configurations were formed from target Gabors in a background of randomly oriented and positioned noise Gabors. *Note:* Please refer to the online version of the article to view the figures in colour.

Table 4. Participants' Details, IQ Scores, and AQ Scores, for the Two Groups in Experiment 2.

	N (Female, Male)	Age (range)	ADOS	Approximate IQ (range; *SD*)	AQ (range; *SD*)
ASD	18 (13, 5)	23.73 (21–30)	12.44 (3.40)	107.73 (82–125; 15.37)	23.21 (16–39; 8.16)
TD	18 (11, 7)	25.67 (19–27)		115.5 (90–120; 8.85)	17.50 (5–22; 4.80)

ASD = autism spectrum disorder; TD = typically developing; ADOS = Autism Diagnostic Observation Schedule.
Note: No significant difference between groups in IQ scores, $t(34) = 1.12$, $p > .1$, and in chronological age, $t(34) = 1.22$, $p > .1$.

Hebrew versions of the Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001), and the short Hebrew version of the Wechsler Intelligence Scale (WAIS-III/WISC-IV) to assess IQ. This short version (Kaufman, Kaufman, Balgopal, & McLean, 1996) includes both verbal and performance intelligence tests that have been shown to yield reliable scores in ASD (Minshew, Turner, & Goldstein, 2005). Consistent with common procedures, the approximate IQ scores were obtained by summing the scores of all four tests, multiplying the sum by 1.6 and adding 36 (Kaufman et al., 1996). Each participant (and participant's guardian, when required) provided written informed consent. The participants were paid 50 ILS for one session of testing that lasted about an hour. The TD participants were recruited through advertisements in the university, and ASD participants were recruited through hostels, assisted living centers, and Internet forums. The participants' details as well as the IQ and AQ scores for the two groups are presented in Table 4. The participants in the ASD group had significantly higher AQ scores, $t(34) = 53.39$, $p < .002$, but did not differ significantly from the typical group in IQ scores, $t(34) = 1.73$, $p > .104$.

Stimuli

The stimuli were generated on a laptop computer using the MATLAB programming environment (version 7.4.0.287. The MathWorks, Inc., Natick, MA, USA) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Mean luminance was 60 cd/m^2. The enclosing and open arc configurations were made up of 12 Gabor patches (Gaussian windowed sinusoidal gratings) each. The Gabor patches were positioned on the imaginary elliptical contour with a random starting point. The position of the contour was jittered up to 2° around the center of the screen so that its elements appeared in different spots but at roughly the same radius so as to minimize positional uncertainty (e.g., Hess & Dakin, 1997, 1999). The Gabor elements were created by multiplying a sine wave grating with a spatial frequency of 3 cycles/degree a circular Gaussian envelope with standard deviation (r) of 0.25°. Contrast within the elements was 88%. The contour was embedded in a field of noise Gabor patches with random orientations that were distributed randomly across the visual field. The screen was divided into imaginary circles of increasing radii, with the number of circles varying with the spacing between the background elements, which was specified by a staircase procedure (i.e., averaged spacing among the background elements decreased over trials by adding circles of background elements). Noise Gabors were assigned randomly to the imaginary radii and the center of each was positioned randomly within ± 5 pixels along the imaginary radius. A new random noise background was generated on each trial. All of the Gabor patches, both background noise and contour elements, were identical physically except for their locations and orientations.

For each type of Stimulus (open, closed), two levels of collinearity of the target contour elements crossed with two levels of spatial proximity. Collinearity was manipulated by jittering the local orientation of the contour elements. This jittering is described by the angle α (Field et al., 1993). Specifically, we used α of 0° and 20° for each proximity level. For $\alpha = 0°$, the orientations of the contour elements were parallel to the imaginary contour. For $\alpha = 20°$, the orientations of the contour elements differed randomly either clockwise or anti-clockwise by α degrees from the imaginary contour. The global curvature of the imaginary contour was kept constant across these different collinearly conditions. Spatial proximity was manipulated by varying the distance among the target contour elements while keeping constant the total number of elements in the background noise display as well as the total number of elements in the target contour. Consequently, changes in spatial proximity cooccurred with changes in the size of the target contour but without changes in the number of elements. Specifically, the distance between the elements in the target contour was set at 1.64° and 2.21° (when viewed from the testing distance of 50 cm).

Procedure

The participants sat approximately 50 cm from the screen and were asked to indicate which of two intervals contained a contour. Each participant completed eight tests (four combinations of collinearity and proximity for each type of arc configuration). The order of the type of configuration (open/closed) was counterbalanced across subjects and the order of the four combinations of collinearity and spatial proximity was determined by a Latin Square. The practice run consisted of one full staircase procedure with perfect collinearity ($\alpha = 0°$) and the level of proximity to be used in the four tests to follow. The participants were instructed to fixate on a 2.17° black circle in the center of the screen at the beginning of each trial. A temporal 2AFC task was employed in which two stimulus displays were presented sequentially. One display contained a contour embedded in a background of randomly oriented noise elements and the other display contained only noise.

The sequence of events on each trial involved an intertrial delay of 300 ms, presentation of the first stimulus display for 500 ms, an interstimulus interval delay of 700 ms, presentation of the second display for 500 ms, a response prompt delay of 200 ms, and a response prompt. The participants indicated which of the two displays contained the contour. Displays containing the contour appeared first or second with equal probability and in random order. Averaged spacing among the background elements was varied according to a one-up, three-down staircase procedure, producing correct response rates equivalent to 79.4% accuracy (Levitt, 1971). In the first display, spacing among the background elements were 1.64° and 2.21°, for high and low proximities, respectively (to produce Δ of 1 in each of these conditions). After three consecutive correct responses, the staircase reduced the spacing of the background elements by 0.1 octave (where an octave is a halving or a doubling of a value). Step size remained at this size until an error was made, at which point step size was reduced to 0.05 octave intervals. Following an error, the staircase reversed directions and a display with a larger spacing was presented until three consecutive correct responses were made, after which the direction of the staircase reversed again to present successively smaller spacing. The testing continued until 10 changes in the direction of the staircase (*reversals*) occurred, which typically required 5 minutes. The threshold for each condition, defined as the minimum spacing among the background elements that permitted accurate discrimination of contour, was based on the geometrical mean spacing of the final six reversals.

Results and Discussion of Experiment 2

To examine the spatial range of contour integration (i.e., effect of spatial proximity) independently from the effect of background spacing, thresholds were converted to delta values (Δ) by dividing them by the contour spacing of the target. A repeated measure ANOVA on the delta values was carried out with stimuli (open, closed), collinearity ($\alpha = 0°$, $20°$), and proximity (high, low) as within-subject factors. Significant differences in delta thresholds reflect limitations in the spatial range of contour integration rather than simply the effect of signal to noise ratio (Kovács, Kozma, Feher, & Benedek, 1999).

Background to contour spacing ratio (Δ values) for the two groups as a function of Gestalt cues are presented in Figure 6. The ANOVA revealed significant differences between groups in Δ values, $F(1, 34) = 5.07$, $p < .032$, indicating higher background to contour spacing ratios for individuals with ASD, suggesting an overall lower tolerance to noise in this group. As expected, the analysis also revealed a significant effect of stimulus, $F(1, 34) = 47.46$, $p < .0001$, and of collinearity, $F(1, 34) = 124.71$, $p < .0001$, on delta values, indicating higher tolerance for dense background elements for closed as compared to open configurations and as collinearity of the contour elements increased. No interactions of any of these cues with group was found to be significant, (all Fs < 1), suggesting again, similar utilization of closure and collinearity in spatial integration in the two groups. Bayes factor calculated on delta values $B_{H[0,\ 0.175]} = .20$ confirmed this null effect of the three-way interaction, again providing evidence that the perceptual organization and grouping processes of persons with ASD are governed by the same interactive relations of spatial proximity and collinearity displayed by their TD peers.

The analysis also revealed a significant effect of spatial proximity, $F(1, 34) = 213.39$, $p < .0001$; however, this effect was qualified by an interaction with collinearity in both groups, $F(1, 17) = 54.14$, $p < .0001$; $F(1, 17) = 193.98$, $p < .0001$, for the ASD and the TD groups, respectively. When contour elements were perfectly collinear ($\alpha = 0°$), no effect of spatial proximity on delta values was observed, $F(1, 34) = .65$, $p > .685$, indicating a relatively strong integration of the elements into a contour, regardless of proximity. As can be seen in Figure 6(a) and (b), the effect of proximity emerged, for both groups, for non-collinear contour elements, $F(1, 17) = 65.41$, $p < .0001$; $F(1, 17) = 1{,}267.4$, $p < .0001$; for the ASD and the TD groups, respectively.

These interactive effects of collinearity and spatial proximity were more robust for the open arc configurations as compared to the enclosing ones, $F(1, 34) = 10.38$, $p < .003$,

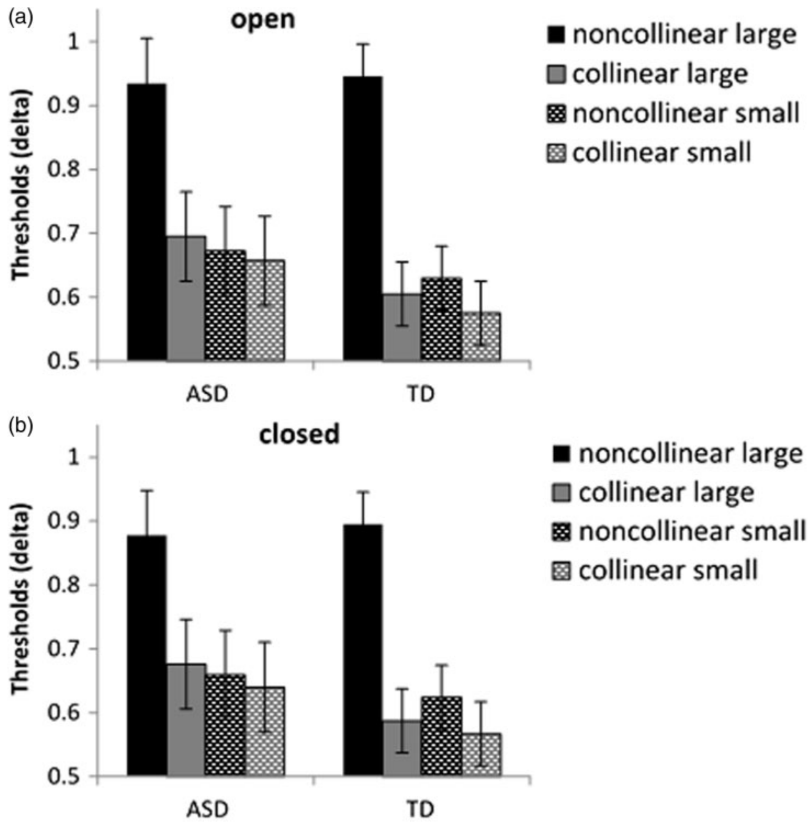

Figure 6. Results for the contour integration task in Experiment 2. Thresholds in terms of delta (background to contour spacing ratio) are plotted as a function of collinearity (collinear vs. noncollinear) and proximity (large vs. small gap), for open (a) and for enclosing (b) arc configurations. Bars indicate 95% within-subject confidence intervals. ASD = autism spectrum disorder; TD = typically developing. *Note:* Please refer to the online version of the article to view the figures in colour.

demonstrating a more detrimental effect of poor spatial proximity for the noncollinear open configurations (Figure 6(a)) than for the noncollinear closed ones (Figure 6(b)). This three-way interaction was not qualified by interaction with group, $F(1, 34) = .89$, $p > .385$, suggesting again that the interactive effects of the Gestalt cues of closure, collinearity, and spatial proximity are similarly manifested in spatial integration among both persons with ASD and MA-matched TD persons.

The findings from the contour integration task demonstrate again the utilization of Gestalt organizational cues in shape formation among persons with ASD. Although they tolerated less noise than the TD participants overall, the participants with ASD exhibited the typical interactive effects of closure, collinearity and spatial proximity, on spatial integration. This converges with the visual search task to show that grouping and segmentation of objects in the environment is governed by the same perceptual cues in the two groups.

These findings are consistent with evidence that contour detection in displays using line configurations (Blake, Turner, Smoski, Pozdol, & Stone, 2003) or Gabor patches (Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006; Kemner et al., 2007) are similar between persons with ASD and MA-matched TD persons. However, group differences have also been noted. For example, Pei et al. (2009) failed to detect a specified neural correlate of contour integration among low functioning children with ASD for displays alternating every 500 ms between circular contours and random patterns. Similarly, Evers et al. (2014) reported that children with ASD were slower and less accurate than typically developing children at identifying contours based on everyday objects. However, these group differences may reflect more generally known differences between the groups in response times and in general tolerance to noise, as demonstrated here, rather than in the mechanism of spatial integration. The studies in this article were designed to identify qualitative differences between groups, and thus were able to provide evidence that the same mechanism of grouping and segmentation, which are based on the same interactive effects of Gestalt cues, governs contour integration in ASD and in TD individuals.

General Discussion

The frequently reported finding of enhanced local processing in ASD, whether indicating an impaired global processing or simply reflecting a perceptual bias, has been typically demonstrated using hierarchical stimuli, in which the global shape can be extracted from the relative position of the local elements (e.g., Badcock et al., 1990; Dakin & Frith, 2005). Accordingly, the ability to determine whether group differences reflect reduced global processing, enhanced local processing, or both is impeded. To provide more conclusive evidence for the ability of individuals with ASD to group local elements or parts into a global shape, we examined grouping of shape in individuals with ASD employing two paradigms in which poor or intact performance could not reflect enhanced local processing. The findings clearly indicated typical shape formation among the participants with ASD. Furthermore, certain interactive relations between Gestalt grouping cues that are known to govern shape formation in TD individuals determined the extraction of the global shape in the participants with ASD. Specifically, individuals diagnosed with ASD with a MA of above 9 years, like their MA-matched TD peers, were able to use closure in an equally efficient manner for the organization of unconnected line segments into a shape, provided that the closure-inducing line segments were in close spatial proximity. Moreover, when the closure-inducing line segments were spatially distant, yielding relatively weak closure, both individuals with ASD and TD ones could utilize collinearity, when available, to enhance closure for the perceptual grouping of shape.

This ability exhibited by the participants with ASD to derive the organized whole representation indicates that the enhanced local processing often observed in ASD reflects a bias rather than impaired integration skills. The ability to utilize the grouping cues of closure, proximity, and collinearity in shape formation further demonstrates the sensitivity of the perceptual system, including among those with ASD, to the statistics of natural scenes. The relation between collinearly and spatial proximity in contour integration, for which individuals with ASD exhibit typical sensitivity, matches well with the edge-alignment structure found in natural images. Collinear segments are better candidates than noncollinear ones for integrating into a unified contour simply because natural contours are relatively smooth (Geisler, Perry, Super, & Gallogly, 2001) and, thus, are more likely to reflect portions of a real object's contour. These types of contours should be integrated even with a large spatial discontinuity between two parts of the contour. An efficient computation of collinearity between elements that is less sensitive to spatial proximity (within a certain range) would, therefore, match the statistics of object contours in the real world. Individuals with ASD appeared to use such a mechanism. Together with other recent studies, these results demonstrate intact sensitivity of the perceptual system of individuals with ASD to the regularities of the outside world (Hadad & Schwartz, 2019).

Although the patterns of results seem to be generally similar for the two groups, we found some subtle differences in performance between the participants with ASD and the TD participants. In the visual search task, the participants with ASD displayed larger slopes as compared to the TD participants under conditions in which search efficiency was also particularly low in the TD group (e.g., open stimuli in Experiment 1a). Similarly, in the contour integration task, thresholds measured in terms of the signal-to-noise ratio were higher among the participants with ASD, indicating lower tolerance to noise for this group. However, these overall differences were more likely to reflect limitations in attentional skills than a difference in the ability to detect and use the structural relations between elements in the Gestalt patterns. The pattern of results showed typical interactive relations among the different Gestalt cues in shape formation among the participants with ASD and, thus, suggests qualitatively similar perceptual organization and shape formation in the two groups.

At first glance, this conclusion seems inconsistent with those from the very few studies on the sensitivity to Gestalt grouping cues among persons with ASD. Specifically, contrary to the present findings, the ability to group based on similarity (Bölte et al., 2007; Falter et al., 2010; Farran & Brosnan, 2011), closure (Bölte et al., 2007; Brosnan et al., 2004), and proximity (Bölte et al., 2007; Brosnan et al., 2004) were found to be impaired among persons with ASD in previous studies. However, these discrepancies may be due to differences in the assessment of grouping between this study and the earlier ones. Grouping in the earlier studies was assessed with tasks in which the participants were required explicitly to introspect on their own grouping perception. Conversely, in our study, grouping was assessed with a visual search task in which the discrimination between target and distractors required grouping of the contour segments into coherent two-dimensional shapes by Gestalt grouping cues. Grouping and shape formation in this case was inferred from search performance with no required explicit report. Concordantly, when tested implicitly using object-based attention effects, grouping by proximity among persons with ASD was, as we found, comparable to that of TD individuals (Falter et al., 2010). Similarly, persons with ASD showed similar effects of Gestalt grouping on perceptual estimations to those displayed by their TD peers on an implicit task of distance estimation examining the organization of visual scenes (Avraam et al., 2019). The convergent evidence from these studies indicates intact utilization of Gestalt cues in element clustering and perceptual organization of visual scenes, and their interactive effects in shape formation. The performance of the participants with ASD on both the visual search and the contour integration tasks also highlights their ability to extract the interactive relations between the different Gestalt cues in order to form a shape. Consistent with Van der Hallen et al.'s (2016) suggestion, these findings point to the importance of task factors in the study of perceptual organization and shape formation among persons with ASD.

Declaration of Conflicting Interests

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ORCID iD

Bat Sheva Hadad https://orcid.org/0000-0002-3159-8696

Notes

1. We set the sample size to match the size we typically use in our studies measuring perceptual processes in ASD employing within-subject designs (e.g., Hadad & Ziv, 2015). Power analysis, based on the effect sizes noted in our pervious experiments in TD (Hadad & Kimchi, 2006), indicated that a sample of 10 individuals would be enough to detect a difference between the critical condition with 80% power and $\alpha = .05$.
2. Power analysis, based on the effect sizes noted in our pervious experiments in TD (Hadad et al., 2010), indicated that a sample of 13 individuals would be enough to detect a difference between the critical condition with 80% power and $\alpha = .05$.

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