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Perceptual grouping abilities in individuals with Autism Spectrum Disorder; exploring patterns of ability in relation to grouping type and levels of development.

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Abstract

The present study further investigates findings of impairment in Gestalt, but not global processing in ASD (Brosnan, Scott, Fox & Pye, 2004). Nineteen males with ASD and nineteen typically developing males matched by non-verbal ability, took part in five Gestalt perceptual grouping tasks. Results showed that performance differed according to grouping type. The ASD group showed typical performance for grouping by proximity and by alignment, impairment on low difficulty trials for orientation and luminance similarity, and general impairment for grouping by shape similarity. Group differences were also observed developmentally; for the ASD group, with the exception of grouping by shape similarity, perceptual grouping performance was poorer at lower than higher levels of non-verbal ability. In contrast, no developmental progression was observed in the typically developing controls.

Introduction

Autism spectrum disorder (ASD) is a developmental disorder, found at all IQ levels, but is often accompanied by learning difficulties (Happé, 1999). Diagnosis is based on impaired social interaction, impaired communication and restricted and repetitive interests and activities (DSM IV, 1994).

Individuals with ASD are reported to show a bias to process the local elements over the global form (e.g. Happé, 1999; Mottron, Belleville & Ménard, 1999; Shah & Frith, 1993). This cognitive style, known as Weak Central Coherence (WCC: Frith, 1989), has been observed in tasks such as the Block Design task (e.g. Wechsler, 1981) and the Embedded Figures task (Witkin, Oltman, Raskin & Karp, 1971), where individuals with ASD show superior performance compared to typical development (Joliffe & Baron-Cohen, 1997; Shah & Frith, 1983; 1993). Similarly, the performance of individuals with ASD on drawing tasks indicates a preference towards producing local elements over the global whole (e.g. Mottron & Belleville, 1993; Mottron et al., 1999; Booth, Charlton, Hughes & Happé, 2002).

There is mixed evidence for the WCC hypothesis. For example, when instructed to direct attention to the global whole, individuals with ASD show evidence of global processing (e.g. Mottron, Burack, Stauder & Robaey, 1999; Plaisted, Swettenham & Rees, 1999) supporting the idea of weak, but not absent, central coherence. Contrary to the WCC hypothesis, there is also evidence of global precedence in ASD (Mottron, Burack, Iarocci, Belleville & Enns, 2003; Rondan & Deruelle, 2007). Alternative accounts of cognitive style in ASD increasingly emphasise the importance of determining the patterns of both strengths and weaknesses in cognitive style in ASD (Happé, 1999; Jarrold, Gilchrist & Bender, 2005; Mottron, Dawson, Soulières, Hubert & Burack, 2006; Plaisted, O’Riordan &

Baron-Cohen, 1998). Thus, in their Enhanced Perceptual Functioning (EPF) hypothesis, Mottron et al. (2006) consider that individuals with ASD show a precedence for local processing, and thus enhanced performance in situations in which, in typical development, global information might interfere with task completion, such as when copying impossible figures (Mottron, Belleville & Mènard, 1999). In contrast, on tasks which require global or multi-feature perception, performance is typical. This difference can explain evidence for both a local bias and for global precedence in ASD.

The current study characterises perceptual grouping performance, which is the ability to group local elements together based on shared properties such as shape similarity or by proximity. Perceptual grouping involves *Gestalt* processing, a form of multi-element perception, in which the grouping together of the local forms is dependent on the positions or visual properties of the local forms themselves for the Gestalt perception to occur. Thus, using the top row of images of Figure 1 as examples, one can observe that the matrix is perceptually grouped into rows or columns based on the similarity of the local elements within each row, and if one were to replace a local element with a different element or adjust the location of a local element, this would disrupt the Gestalt percept. We have targeted this type of global processing because, based on the results of Brosnan, Scott, Fox and Pye (2004), we anticipate that perceptual grouping will be atypical in ASD. In their group of children with ASD, Brosnan et al. (2004) report significantly poorer performance when processing three Gestalt grouping principles, proximity, luminance similarity and closure, relative to children with moderate learning difficulties matched by chronological age and verbal mental age. This finding compared to no group difference in performance when perceiving hierarchical Navon figures, which require global, but not Gestalt processing.

Neural evidence demonstrates differences in activation in typical adults for grouping by proximity compared to grouping by shape similarity (Han et al., 2005a, b). This evidence suggests a strong rationale for examining grouping types separately in individuals with ASD. Many theories of ASD allude to specific structural deficits within the medial temporal lobe (such as the amygdala) (see Penn, 2006). While it is important to take brain plasticity into account because functions can develop along atypical neural pathways (see Karmiloff-Smith, 2009), these differences in activation can be used to make predictions of possible patterns of performance in ASD. As the medial temporal lobe is activated in typical development for grouping by shape similarity, but not for grouping by proximity (Han et al., 2005a, b), neural disruption within this area in individuals with ASD might predict atypical grouping by shape similarity compared to proximity grouping. In support of this, Falter, Plaisted, Grant and Davis (2010) report that, when grouping by proximity is presented in competition with grouping by similarity (in this instance, colour similarity), adolescents with ASD show a stronger preference towards proximity grouping over similarity grouping than typically developing adolescents of the same chronological age. Furthermore, a study examining a range of psychiatric disorders, which employed similar tasks to Brosnan et al. (2004), demonstrated impaired perceptual grouping in high functioning autism, and provides support for the contention that the Gestalt grouping principle of similarity may be a particular weakness in high functioning autism (Bölte, Holtmann, Poustka, Scheurich & Schmidt, 2007).

Brosnan et al. (2004) employed a battery of tasks, which all required Gestalt processing. These were: matrices (e.g. 3x4, or 4x5) grouped into rows or columns by proximity or luminance; single rows of elements, arranged into pairs by proximity or closure, and two tasks involving possible and impossible figures. Bölte et al. (2007) employed matrices to investigate luminance, single rows of elements to investigate proximity and Kanizsa triangles to investigate closure. Falter et al. (2010) employed single rows of stimuli which could be grouped into pairs based on either proximity or colour similarity. The present study is designed to extend our knowledge of Gestalt processing in ASD. First, we have increased the number of Gestalt grouping principles explored to five. Second, we assess these principles using tasks with the same demands and the same number of trials across Gestalt principles. Third, the tasks have a graduated difficulty that varies the strength of the grouping. Fourth, as the experimental task is non-verbal, we have matched the ASD group to typically developing controls by non-verbal ability. That is, we are matching participants by performance in the same domain of cognition as the experimental task. Finally, developmental differences have been demonstrated between global and configural (understanding the spatial relationships between local elements) processes in ASD. That is, global processing improves with maturation, but configural processing does not (Deruelle et al., 2004; Rondan & Deruelle, 2004). As such, Gestalt processing is also analysed with reference to level of non-verbal ability.

WCC and EPF hypotheses predict uniform impairment or typical performance in ASD respectively. However, the analytical approach of this study will lead to a deeper understanding of perceptual abilities in ASD. In light of structural deficits of the medial temporal lobe in ASD, and the functional activation demonstrated in typical development by Han and colleagues (Han et al., 2005a, b), if one assumes associated brain-behavioural impairments, one might predict group differences in the shape similarity grouping variable, which might extend to the other similarity grouping variables (luminance and orientation), whilst the remaining grouping types, proximity and alignment, might be relatively less impaired.

Method

Participants

Nineteen male participants with high functioning Autistic Spectrum Disorder (ASD) and a mean age of 12 years 11 months (S.D.=1;07 years; months) took part. All participants were contacted via their schools. ASD is not a description within DSM-IV, and some participants had a formal diagnosis of Asperger Syndrome, whilst others had a diagnosis of Autism. Diagnosis was made through diagnostic agreement by a multidisciplinary team of clinicians. All participants were attending Secondary Schools in the UK, being exposed to the Key Stage 3 syllabus (ages 11-13). There are no national assessments of academic attainment at Key Stage 3 (e.g. SATs) and academic attainment was not identified for participants. To provide an index of verbal and non-verbal abilities, all participants completed the short form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999); this involves a verbal Vocabulary subtest and a non-verbal Matrix Reasoning subtest. As the Matrix Reasoning subtest is considered an appropriate approximation of general non-verbal ability by the WASI test battery, we consider it a suitable measure by which to match participant groups. As such, a control group of nineteen male typically developing (TD) participants were individually matched to the ASD participants by raw score (±0 to 5) on the non-verbal Matrix Reasoning subtest. Independent samples t-tests confirmed that the groups were suitably matched, $t(36)=.09$, $p=.93$. The TD group were recruited through their schools and were reported by parents and the school to be free of any psychiatric diagnosis. At a group level the ASD and TD groups were also matched by Chronological Age (CA), t(36)=-1.18, p=.25. The TD group had a mean age of 12 years and 4 months (S.D.=1;01 years; months). Participant details are shown in Table 1.

Table 1 about here

Design and Procedure

For each trial, participants were presented with an image containing an arrangement of 49 elements in a 7 by 7 formation as shown in Figure 1. For the proximity task, for more proximal trials additional elements were included to prevent differences between the vertical and horizontal dimension cueing responses. Images were presented at a viewing distance of 30 cm such that each image subtended a visual angle of 14.6° x 14.6° and the diameter of each local element subtended a visual angle of 1.1°. Participants were asked whether the stimuli were grouped horizontally or vertically and to respond by pressing one of two response buttons, which were labelled with a horizontal or vertical two-headed arrow. In order to provide feedback, stimuli remained on the screen until a correct response had been provided. The stimulus was then replaced by a 500 msec. mask before the next trial began (the mask was designed to erase any after images, or feed-forward effects of the previous stimuli). Five types of perceptual grouping were employed; grouping by alignment, grouping by proximity and three types of grouping by similarity; shape, luminance and orientation. Each grouping type was tested separately, with order of grouping types counterbalanced and 50% of trials were grouped vertically and 50% showed horizontal grouping of elements. For each grouping type there were four practise trials and 20 experimental trials, with the exception of grouping by shape similarity where, due to a computer error, data was recorded for four practise trials and 18 experimental trials. The experimental trials included four trials at each of five levels of difficulty. These were sequentially presented in three blocks of increasing difficulty level, with trials within each block randomised. Blocks included four (level 1), eight (levels 2 and 3) and eight trials (levels 4 and 5) respectively (for the shape similarity task, data from 3 trials only were recorded for levels 2 and 5). Each set of four practise trials could be repeated if a participant failed to understand the procedure. However, this was not necessary.

Grouping by Alignment: Individuals were presented with a grid of unfilled circles. They were asked to indicate whether the elements were aligned in a straight line horizontally or vertically. Each circle had a diameter of 20 pixels, and when aligned, circles were spaced by a 20 pixel gap. Task difficulty increased sequentially according to the extent to which the elements were misaligned. Along each column or row, 4 or 3 elements were misaligned in the same direction, whilst the remaining elements did not change position. Approximately 50% of the 49 elements were misaligned (24 or 25 elements). In the practise trials (block 0) and the first four experimental trials (block 1), misalignment was by nine pixels (level 1). For block two, misalignment was by eight or seven pixels (levels 2 and 3), and in block three, misalignment was by six or five pixels (levels 4 and 5). Each increment of misalignment was employed twice as a row, and twice as a column.

Grouping by Proximity: Participants were shown a grid of unfilled circles, 20 pixels in diameter. These were grouped together horizontally or vertically by proximity. Arrangements were a standard seven circles, 20 pixels apart in one dimension, horizontal or vertical, but were more proximal in the opposing dimension. In the four practise trials (block 0) and the first four experimental trials (block 1, level

1), nine circles were spaced ten pixels apart in the more proximal dimension. In block two, circles were proximal by 12 or 14 pixels (levels 2 and 3) in one dimension and the number of circles in more proximal dimension was nine or eight. For block three, circles were proximal by 16 or 18 pixels (levels 4 and 5). The number of circles in the more proximal dimension was seven circles.

Grouping by similarity: For the three types of grouping by similarity, the spatial location of each element remained constant (spaced 20 pixels apart), thus grouping was defined by the visual identity of the elements. For grouping by shape similarity, elements were either squares or circles. For grouping by luminance, elements were black and white circles. For grouping by orientation, single lines were presented at either 0° orientations (vertically upright) or slanted 30° clockwise. Difficulty was increased by introducing distracter elements which conflicted with the grouping of the remaining elements. For each type of grouping by similarity, the practise trials (block 0) and the initial four experimental trials (block 1, level 1) had no distracting stimuli. For the remaining trials two, four, six or eight distracting elements were present, two of each grouped by rows or by columns respectively. Block two included trials with two or four distracting elements (level 2 and 3) and block three had trials with six or eight distracting elements (levels 4 and 5).

This number of trials extends significantly beyond the number used by Brosnan et al. (2004) and has been found to be the appropriate quantity for eliciting differences in Gestalt processing in Williams Syndrome (Farran, 2005).

Figure 1 about here

Results

Results are reported according to proportion correct. One-sample t-tests against a maximum and minimum proportion correct of one and zero respectively, showed that both groups scored significantly below ceiling and above chance for each of the five grouping types (p<.05 for all). However, one participant with Autistic Spectrum Disorder (ASD) scored consistently below chance on the grouping by orientation similarity task, which suggests that they were not carrying out the task appropriately. The proportion correct values for this person were replaced with the mean proportion correct values of the ASD group, for this task.

As the tasks were not equated for overall level of difficulty, performance on each task is first analysed separately. This analysis is followed by an across task comparison, in which the pattern of performance of the Typically Developing (TD) control group is taken into account, as an index of task difficulty level. Finally, performance is assessed developmentally in relation to level of non-verbal ability.

Individual task analysis

For each of the five grouping types, a two factor ANOVA, with a within participant factor of difficulty level (5 levels), and a between participant factor of group (TD, ASD) was carried out. For some tasks, although overall performance was not at ceiling as indicated above, performance was at ceiling for specific levels of difficulty. Performance means and standard deviations for each grouping type at each difficulty level are shown in Table 2.

Table 2 about here

Grouping by Alignment

No main effects or interactions were observed (group: F<1; difficulty: F(4, 144)=1.17, p=.33, η_p^2=.03; difficulty by group: F<1).

Grouping by Proximity

There was no main effect of group (F<1). There was a main effect of difficulty, due to decreasing accuracy with increasing difficulty level (reported as a linear contrast, F (1, 36) =29.43, p<.001, η_p^2=.23). This effect did not interact with group, F(4, 144)=1.22, p=.31, <1, η_p^2=.03.

Grouping by Shape similarity

There was an effect of group (F(1, 36)=6.59, p=.02, η_p^2=.16) due to poorer performance in the ASD group than the TD group. There was no main effect of difficulty (F(4, 144)=1.74, p=.15, η_p^2=.05) or interaction between difficulty and group (F<1).

Grouping by Orientation similarity

There were no main effects (group: F<1; difficulty: F(4, 144)=1.33, p=.26, η_p^2=.04), but the interaction between difficulty and group was significant: F(4, 144)=2.62, p=.04, η_p^2=.07, due to significantly poorer performance in the ASD group than the TD group for the easiest difficulty level only (level 1: p=.045; levels 2 to 5: p>.05 for all).

Grouping by Luminance similarity

There were no main effects (group: F<1; difficulty: F(4, 144)=1.21, p=.31, η_p^2=.03), and the interaction between difficulty and group was marginal: F(4, 144)=2.11, p=.08, η_p^2=.06. Although marginal, further exploration of the interaction revealed a similar pattern to that observed for orientation similarity: performance was significantly poorer in the ASD group than the TD group for the easiest difficulty level only (level 1: p=.04; levels 2 to 5: p>.05 for all).

Across task analysis

The following analysis determines how the performance of the ASD group varies across tasks, relative to the TD control group. As performance varies across tasks for the TD control group, a between groups comparison is not appropriate as it would be difficult to compare the extent to which any differences in the absolute level of ability reflected impaired or unimpaired performance in the ASD group, relative to the TD controls. Therefore, proportion correct values (collapsed across difficulty level) of the ASD group were transformed for each task into z-scores on the basis of the performance of controls (also collapsed across difficulty level), for that task. This technique partials out any difference in the relative difficulty across the tasks that occur in typical development; for all tasks, typical performance is represented by a mean of zero and a standard deviation of 1. A one-way ANOVA was carried out on the z-scores of the ASD group with one within-participant factor of grouping type (5 levels). The main effect of grouping type was significant, $F(4, 72)=4.94$, $p=.001$, $\eta_p^2=.22$. Pairwise comparison revealed that the effect was due to significantly lower z-scores for grouping by shape similarity compared to the other grouping types only (shape < alignment, proximity, orientation, luminance, $p<.05$ for all; all other comparisons, $p>.05$). One-sample t-tests against a score of zero, also demonstrated that grouping by shape similarity was the only grouping type that was significantly different from typical performance (shape similarity, $p=.01$, all other grouping types, $p>.05$). Z-scores are illustrated in Figure 2.

Figure 2 about here

Developmental trajectory analysis

Two sets of analyses were conducted. First, overall proportion correct (collapsed across perceptual grouping types) was subjected to linear regression analysis for the TD and ASD groups separately to determine whether performance was related to Non-verbal raw score (NVS), the measure by which the groups were matched. This score was rescaled to start from the lowest NVS of the ASD group, which does not change the analysis, but aids interpretation of intercepts, as it relates to values within the range of values of the data set employed (see Thomas et al., 2009). Overall proportion correct was related to NVS for the ASD group (R^2=.44, F(1, 18)=13.28, p=.002), but not the TD group (F<1). For the ASD group, perceptual grouping performance was stronger with increasing NVS (interestingly, a similar pattern was observed for Chronological Age, ASD: R^2=.21, F(1, 18) = 4.52, p=.05; TD: F<1). In order to determine whether the lack of significance in the TD group was due to there being either no relationship between NVS and performance, or a linear relationship with a gradient of zero, the data were rotated by 45° (see Thomas et al., 2009) and showed no relationship between NVS and perceptual grouping performance (R^2=.06, F(1, 18)=1.06, p=.32), which indicates that for the TD group perceptual grouping ability is not related to change in NVS (within the range of NVS of the TD group employed).

As TD performance is not related to NVS, trajectories cannot be compared statistically between groups. Inspection of the linear function for performance against NVS (remember, these are scaled to the lowest NVS of the ASD group) for the ASD group, indicates that at the lowest NVS the ASD group were correct on 65.9% of trials and indicates delayed abilities in the ASD group, relative to TD performance (mean: 86%; range: 73% to 95%). For the ASD group, the linear function showed a 1.3% increase in performance per each additional non-verbal score, which compared to no (0.1%) change with NVS for the TD group. Thus, although at the beginning of the NVS trajectory the ASD group commenced from a lower perceptual grouping score, differences in developmental relationships for each group demonstrate that, at higher levels of non-verbal ability, their level of perceptual grouping performance can be said to have ‘caught up’ with that of the TD group, who do not show performance changes with increasing NVS. Trajectories of perceptual grouping ability plotted against NVS are illustrated in Figure 3.

The second set of analyses determines whether the relationship between performance and NVS differs across grouping types for the ASD group. As shown in the across task analysis, grouping by shape similarity is weak in ASD relative to the typical population, thus one might expect difference in developmental trajectories across tasks. Due to the lack of relationship between TD performance and NVS, between group comparisons could not be made, and so ASD performance cannot be compared statistically to the TD group. ANCOVA was carried out for the ASD group data, with the additional factor of grouping type (5 levels). As in the above analyses, a rescaled NVS was employed, and this was entered as the covariate. Interestingly, results showed that for the ASD group, grouping type interacted with NVS (ASD: $F(4, 68)=2.91$, $p=.03$, $\eta_p^2= 0.15$. Although not strictly appropriate, it is interesting to note that the equivalent analysis for the TD group showed no such interaction ($F<1$), indicating that, in typical development, no relationship is observed between performance and NVS for any grouping type. For the ASD group, further analysis showed that performance was related to NVS for all grouping types, with the exception of grouping by shape similarity, thus further differentiating grouping by shape similarity from other grouping types: shape similarity: $R^2=.05$, $F<1$; luminance similarity: $R^2=.26$, $F(1, 18)=5.88$, $p=.03$; orientation similarity: $R^2=.53$, $F(1, 18) = 19.39$, $p<.001$; Proximity: $R^2=.24$, $F(1, 18)=5.37$, $p=.03$; Alignment: $R^2=.24$, $F(1, 18)=5.37$, $p=.03$). When rotated, grouping by shape similarity did not show a zero trajectory for the ASD group (R^2=.01, F<1), and thus performance on this grouping type is not related to NVS. Trajectories of performance for each group, on each grouping task are illustrated in Figures 4a and 4b.

Figures 3, 4a and 4b about here

Discussion

This study expands upon Brosnan et al. (2004), by employing a wider range of Gestalt grouping principles and by using a consistent task design across grouping principles. Results showed only one grouping type, grouping by shape similarity, in which the Autistic Spectrum Disorder (ASD) group performed at a lower level than the typically developing (TD) group across *all* levels of the task. Impaired performance in the ASD group was also observed for level 1 trials only (when there were no distracter stimuli) for grouping by orientation similarity. Although only supported by a marginal interaction, a similar group difference was also observed at level 1 for grouping by luminance similarity. Thus, for the pure grouping trials, which were akin to the matrices tasks employed by Brosnan et al. (2004), individuals with ASD demonstrated poor grouping ability for all types of similarity grouping. In contrast, for grouping by proximity and by alignment, the ASD group performed at the level of TD controls.

The results of the present study show some consistency to Falter, Plaisted Grant and Davis (2010) and Bölte et al. (2007) who also showed impaired similarity grouping in ASD. Falter et al. (2010) demonstrated an advantage for grouping by proximity over colour similarity in their ASD group which was not present in the TD group. Bölte et al. (2007) employed one type of similarity grouping (grouping by luminance) and report a particularly large effect size showing impaired performance in adults with high functioning autism, relative to adult controls of the same level of non-verbal and verbal ability. By exploring three types of similarity grouping, the current study extends the above findings to suggest that a deficit in grouping by similarity is observed for multiple types of similarity in ASD, with the most consistent deficit for grouping by shape similarity. In the current study, grouping by shape similarity further differentiated from the remaining four grouping types developmentally; for the ASD group, progression in grouping ability was observed with increasing non-verbal ability for all grouping types except for grouping by shape similarity. Taken together these results provide tentative evidence that the grouping principles argued to be supported by the medial temporal cortex in the typical population (Han et al., 2005a, b) are specifically atypical in ASD. These findings also provide a potential link between social components of the ASD phenotype and the non-social components assessed here, both of which are functions of the medial temporal lobe in the typical population. Further understanding of developmental brain-behaviour interactions and functional cortical specialisation in ASD could examine this possible connection.

At first look, our results do not fully support Brosnan et al. (2004), as we did not find an overall impairment in Gestalt processing in ASD. Brosnan et al. (2004) did not utilise ‘distracters’ and their stimuli were therefore closest to level 1 (no distracters) in the present study. Thus, one could argue that the disparity across studies relates to proximity only. However, as the group difference for grouping by luminance is supported by a marginal interaction, this suggestion is tentative. A stronger interpretation for the differences in findings relates to the developmental progression of perceptual grouping ability which demonstrates that at the beginning of the developmental trajectory, where level of non-verbal ability is lowest, individuals with ASD show lower perceptual grouping abilities than the control group, but as non-verbal ability develops, this discrepancy between the groups disappears**.** Brosnan et al. (2004) assessed low functioning individuals with ASD, and thus their results reflect the low end of non-verbal abilities, and hence show a discrepancy between Gestalt grouping abilities in ASD and their control group of individuals with moderate learning difficulties. In contrast and in support of the present results, in individuals with ASD with IQ within the normal range, Blake, Turner, Smoski, Pozdol & Stone (2003) and Mottron et al. (1999) report typical perceptual grouping by good form in individuals with ASD, relative to TD controls. Coupled with Falter et al.'s (2010) results, which were also from individuals with a Mental Age not dissimilar to their Chronological Age, the present results emphasise the importance of taking level of ability into account. Indeed, level of ability in ASD has been shown to impact many domains, for example, within the visuo-spatial domain, areas such as face processing (Annaz, Karmiloff-Smith, Johnson & Thomas, 2009; Riby, Doherty-Sneddon & Bruce, 2008) and gaze following (Leekam, Hunnisett & Moore, 1998).

The patterns of performance across the five levels of difficulty show a linear reduction in performance for grouping by proximity and uniform performance for grouping by alignment for both the TD and ASD groups. Whilst the manipulation to proximity and alignment stimuli was integral to the grouping itself, this kind of manipulation is not always possible for grouping by similarity. For the three similarity tasks neither group showed evidence of a linear reduction in accuracy across difficulty levels, i.e. the increase in the number of distracters did not have the desired linear effect on difficulty. Despite this, above chance performance indicates that participants were able to perceptually group the elements at all levels.

It is possible that there was a qualitative difference on similarity tasks between level 1 where perceptual grouping could be carried out pre-attentively, and levels 2 to 5 where perceptual grouping was disrupted by distracter stimuli. For grouping by orientation similarity and luminance similarity, the TD group made fewer errors than the ASD group for level 1 trials, but performance was similar between the groups when distracter stimuli were added (levels 2 to 5). The group difference in patterns of performance could imply that the introduction of distracters required a change in processing demands for the TD, but not the ASD group. Take, for example, the level 3 grouping by orientation example displayed in Figure 1. Typically, a general impression of grouping by rows is perceived. However, attention is also drawn to the distracter stimuli, which requires the rows in which they are embedded to be re-evaluated before a conclusion can be reached. This processing sequence contrasts to level 1 stimuli, for which this second step is not necessary, and thus erroneous responses are minimal. If individuals with ASD have Enhanced Perceptual Functioning (Mottron et al., 2006) they might rely on this skill alongside their perceptual grouping abilities throughout, and thus, in contrast to the typical population, responses at all levels would have some weighting towards comparisons across the local features within each row or column. As this would not differentiate level 1 trials from the remaining trials, this could explain the group difference for these trials. Different strategy use in ASD is supported by Stroganova et al. (2007) who demonstrated similar behavioural responses, but dissimilar neural responses for grouping by closure in participants with ASD, relative to Chronological Age matched TD controls.

If one considers performance on the pure grouping trials only (level 1 trials), the data support Falter et al.'s (2010) assertion that perceptual grouping performance in ASD can be differentiated according to a distinction made by Pomerantz (1983) between Type P relationships which relate to the spatial position of items, and type N relationships in which grouping is determined by the visual identity of each item. In this study, for level 1 trials, grouping by similarity (Type N relationships) is weaker than grouping by proximity and alignment (Type P relationships) for the ASD group, relative to typical development. However, this assertion is supported with caution because both groups were able to perceptually group to a similar extent for luminance and orientation similarity grouping when distracter stimuli were introduced.

Grouping by shape similarity shows a typical *pattern* of performance across difficulty levels in the ASD group. This finding suggests that participants chose to rely on more typical strategies for this grouping type, but with detrimental effects on performance. This hypothesis is also supported by the developmental trajectory analysis, where the ASD group show a lack of relationship between performance and non-verbal ability as observed for the TD group. Bott, Brock, Brockdorff, Boucher and Lamberts (2005) show evidence that individuals with ASD do not discriminate between different shapes in a typical manner. The authors demonstrated that perceptual similarity judgements for different rectangle shapes marginally differed for individuals with ASD compared to TD controls; the ASD group employed fewer dimensions for similarity judgement than the TD group. Although we do not know whether this is specific to just this form of Gestalt similarity, it does offer some explanation for the impairment in grouping by shape similarity in the current study. Indeed, introducing a strategy based on Enhanced Perceptual Functioning would not be advantageous if discrimination between local features is problematic.

The relationship between perceptual grouping and non-verbal ability which is present for the ASD group in four of the five grouping types measured, further suggests that many forms of perceptual grouping are not accomplished using typical strategies in ASD. For the TD group, level of non-verbal ability had no relationship to perceptual grouping ability. As perceptual grouping is available within the first few months in typical development (e.g. Farroni et al., 2000; Farran et al., 2008; Quinn & Bhatt, 2005) one would predict that these abilities would be fully developed for the age group measured here. In contrast, although individuals with ASD can perform perceptual grouping, the developmental progression observed here questions whether tasks were completed using typical strategies.

The present pattern of results is encouraging, as it suggests that, with development of non-verbal ability, individuals with ASD can develop perceptual grouping abilities. Although one must note that development of this ability is affected by the limitations in cognitive maturation of each individual. These findings also further characterise visuo-spatial cognition in ASD; Gestalt processing can no longer be thought of as a relative deficit across the full spectrum of abilities in ASD as, with the exception of grouping by shape similarity, this deficit is related to maturation. Developmental exploration of global processing using the Navon task has shown that global processing also becomes more typical as development progresses in ASD (Deruelle, Rondan, Gepner & Tardif, 2004; Rondan & Deruelle, 2004; also see Edgin & Pennington, 2005). This pattern contrasts to configural processing, where no developmental progression is observed in ASD (Rondan & Deruelle, 2004, 2007). Rondan and Deruelle (2004, 2007) demonstrated that, when presented with schematic face stimuli and geometric shapes, children and adults with ASD show an atypical preference to detect local changes (changes in the identity of elements) over configural changes (changes in the spatial relationship between local elements). The difference in the developmental trajectories of configural processing measured by

Rondan & Deruelle (2004, 2007) and Gestalt processing measured here contradicts Rondan and Deruelle’s (2007) assumption that these two processing types overlap. The difference suggests that they should be considered independently, or that there might be independent effects of particular task demands. It seems that whilst individuals with ASD can group stimuli based on the proximity between the local elements in the array, this does not extend to detecting configural changes between some of the local elements within a more complex configuration (such as a schematic face or geometric shape).

The present results add to previous findings which cannot support the Weak Central Coherence hypothesis (Frith, 1989), and we have presented speculative hypotheses in relation to Enhanced Perceptual Functioning (Mottron et al., 2006). The pattern of results, however, suggest that broad theories are not able to fully explain the cognitive abilities of ASD, but that further research is required to truly elucidate the cognitive styles and strategies employed in ASD. It is also possible that differences in the subtypes of ASD (e.g. Asperger Syndrome and High Functioning Autism) may differ in aspects of Enhanced Perceptual Functioning. However, as language delay typically distinguishes these two sub groups, it is likely that differences between these subtypes reside in auditory processing (Bonnel et al., 2010), rather than visual processing. The number of participants in the present study was too small to identify potential subtype differences within visual processing, but this should be born in mind when considering the differences between the ASD group and controls.

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Table 1: Participant details

	CA(years; months) mean (S.D.)	Non-verbal score: mean (S.D.)	Verbal score: mean (S.D.)	Full Scale IQ: mean (S.D.)
ASD (N=19)	12; 11 (1;07)	26.26 (6.23)	50.54 (13.85)	109.53 (18.31)
TD (N=19)	12;04 (1;01)	26.42 (4.19)	41.11 (11.20)	101.84(13.39)

Table 2: Proportion correct for each group across perceptual grouping tasks and difficulty level: Mean (standard deviation).

Grouping type	**Group**	**Difficulty level**				
		level 1	level 2	level 3	level 4	level 5
alignment	TD	0.79(0.28)	0.83(0.22)	0.82(0.22)	0.83(0.26)	0.79(0.28)
	ASD	0.74(0.28)	0.79(0.29)	0.79(0.27)	0.80(0.26)	0.70(0.31)
proximity	TD	0.78(0.25)	0.86(0.21)	0.76(0.24)	0.55(0.27)	0.47(0.25)
	ASD	0.78(0.32)	0.72(0.29)	0.66(0.31)	0.55(0.26)	0.50(0.22)
orientation	TD	0.96(0.09)	0.92(0.15)	0.88(0.23)	0.93(0.14)	0.88(0.19)
	ASD	0.83(0.25)	0.92(0.17)	0.94(0.13)	0.92(0.24)	0.85(0.28)
luminance	TD	0.99(0.06)	0.99(0.06)	0.91(0.19)	0.92(0.12)	0.96(0.09)
	ASD	0.92(0.12)	0.96(0.09)	0.95(0.10)	0.96(0.09)	0.95(0.10)
shape	TD	0.99(0.06)	0.96(0.11)	0.97(0.08)	0.97(0.08)	0.93(0.14)
	ASD	0.95(0.10)	0.88(0.20)	0.86(0.21)	0.91(0.15)	0.86(0.23)

Figure Captions

Figure 1: Perceptual grouping stimulus types, and levels of difficulty

Figure 2: Perceptual grouping z-scores of proportion correct: mean and standard error

Figure 3: Perceptual grouping proportion correct collapsed across tasks, plotted against NVS.

Figure 4a: Perceptual grouping proportion correct for the ASD group, plotted for each grouping task, against NVS

Figure 4b: Perceptual grouping proportion correct for the TD group, plotted for each grouping task, against NVS

Figure 1

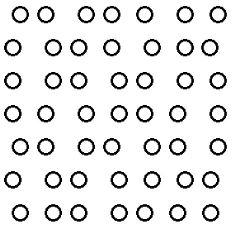
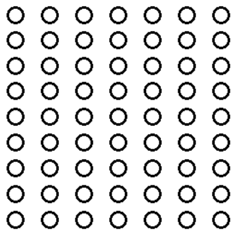
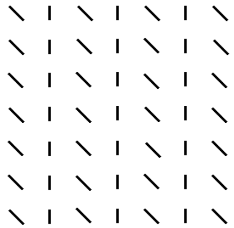
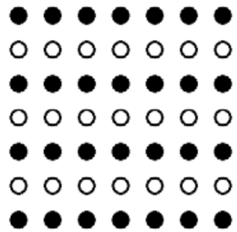
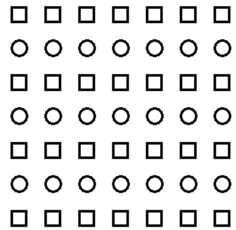
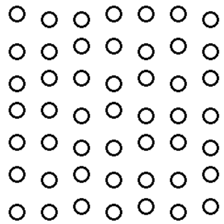
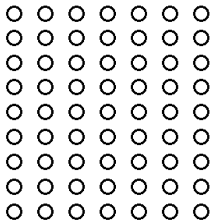
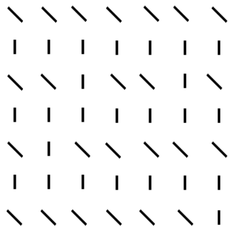
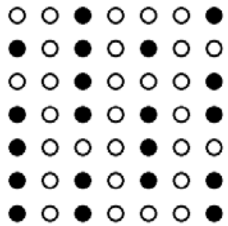
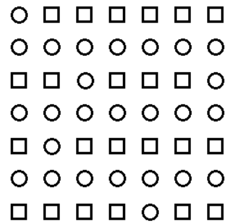
Grouping type	**Alignment**	**proximity**	**Orientation similarity**	**Luminance similarity**	**Shape similarity**
					
Grouping	horizontal	vertical	vertical	horizontal	horizontal
Level	1	1	1	1	1
Level description	Misalignment: 9 pixels	Spacing: 10 pixels	Distracter elements: 0	Distracter elements: 0	Distracter elements: 0
					
Grouping	vertical	vertical	horizontal	vertical	horizontal
Level	3	2	3	5	4
Level description	Misalignment: 7 pixels	Spacing: 12 pixels	Distracter elements: 4	Distracter elements: 8	Distracter elements: 6

Figure 2

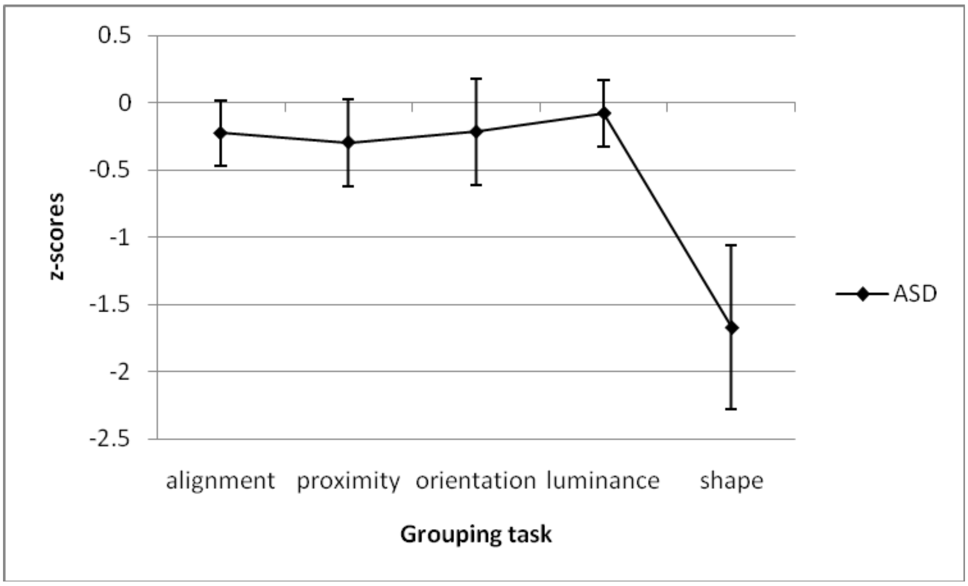

0.5
0
-0.5
-1
-1.5
-2
-2.5
z-scores
alignment
proximity
orientation
luminance
shape
Grouping task
ASD

Figure 3

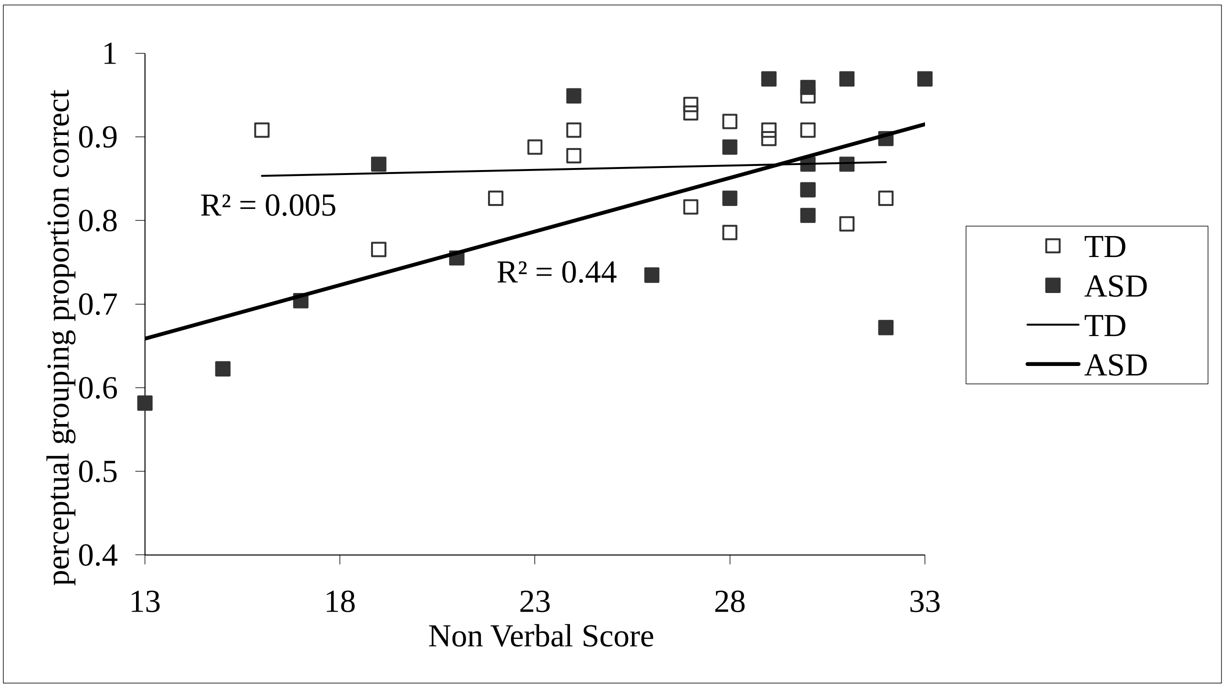

1
0.9
0.8
0.7
0.6
0.5
0.4
perceptual grouping proportion correct
13
18
23
28
33
Non Verbal Score
R² = 0.005
R² = 0.44
TD
ASD
TD
ASD

Figure 4a

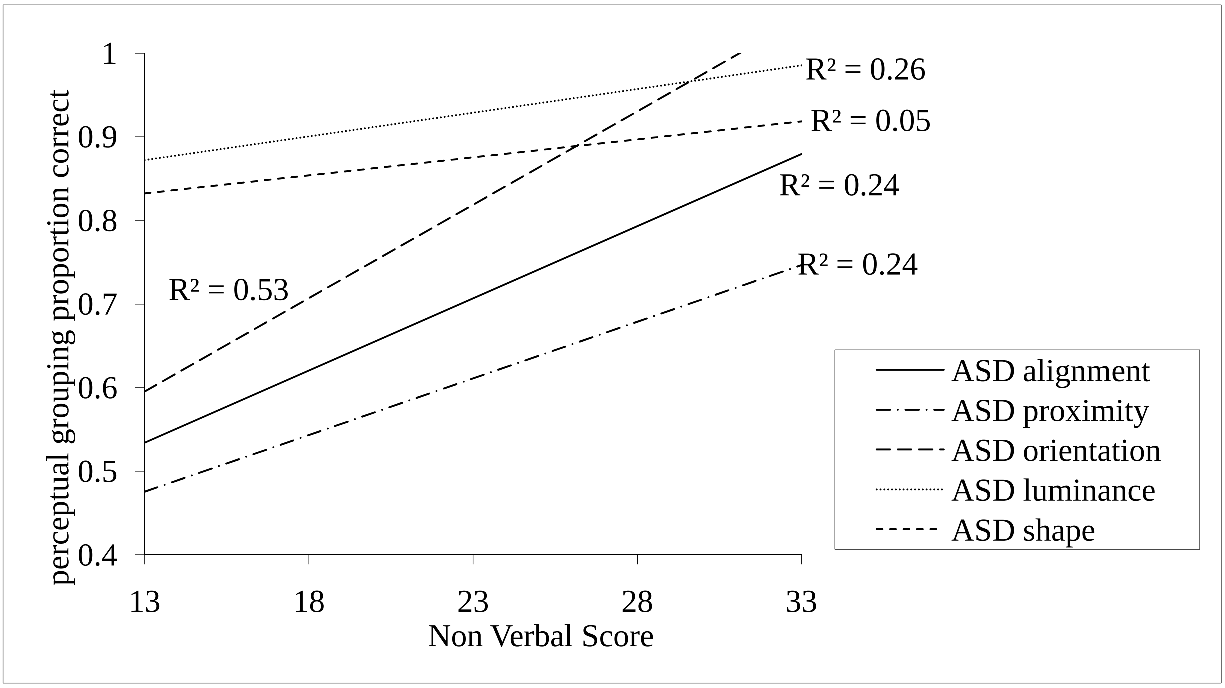


Figure 4b