RUNNING HEAD: Perception, Drawing and Construction.

Perceptual Grouping and Distance Estimates in Typical and Atypical Development: Comparing Performance across Perception, Drawing and Construction Tasks.

Emily K. Farran[1], Victoria L. Cole[2]

[1] School of Psychology and Clinical Language Science, University of Reading

[2] Department of Psychology, University of Oxford

Address correspondence to:

Emily Farran
School of Psychology and Clinical Language Science
University of Reading
Earley Gate
Reading
RG6 6AL
UK
Tel: +44 (0)118 378 7531
Fax: +44 (0)118 931 6715
E-mail: E.K.Farran@reading.ac.uk

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Abstract

Perceptual grouping is a pre-attentive process which serves to group local elements into global wholes, based on shared properties. One effect of perceptual grouping is to distort the ability to estimate the distance between two elements. In this study, biases in distance estimates, caused by four types of perceptual grouping, were measured across three tasks, a perception, a drawing and a construction task in both typical development (TD; Experiment 1) and in individuals with Williams syndrome (WS; Experiment 2). In Experiment 1, perceptual grouping distorted distance estimates across all three tasks. Interestingly, the effect of grouping by luminance was in the opposite direction to the effects of the remaining grouping types. We relate this to differences in the ability to inhibit perceptual grouping effects on distance estimates. Additive distorting influences were also observed in the drawing and the construction task, which are explained in terms of the points of reference employed in each task. Experiment 2 demonstrated that the above distortion effects are also observed in WS. Given the known deficit in the ability to use perceptual grouping in WS, this suggests a dissociation between the pre-attentive influence of and the attentive deployment of perceptual grouping in WS. The typical distortion in relation to drawing and construction points towards the presence of some typical location coding strategies in WS. The performance of the WS group differed from the TD participants on two counts. First, the pattern of overall distance estimates (averaged across interior and exterior distances) across the four perceptual grouping types, differed between groups. Second, the distorting influence of perceptual grouping was strongest for grouping by shape similarity in WS, which contrasts to a strength in grouping by proximity observed in the TD participants.

Introduction

One way in which we organise our visual world is to group local elements within the visual array together into global wholes. This process is known as perceptual grouping and is based on shared properties or gestalt principles (e.g. Kohler, 1929; Wertheimer, 1923). For example, elements can be grouped together by similarity such as luminance, shape or size similarity, by shared movement (common fate), good form (elements form continuous lines or contours) or by proximity. The purpose of perceptual grouping is to direct attention towards relevant parts of the visual array, and to facilitate object recognition (Gillam, 2001).

Perceptual grouping was originally considered to be a single innate mechanism (e.g. Wertheimer, 1923). However, it is now known that different types of perceptual grouping develop and operate separately. For example, different forms of perceptual grouping emerge at different time points in infancy (e.g. Farroni, Valenza & Simion, 2000; Kellman & Spelke, 1983; Quinn & Bhatt, 2005). Similarly, at a neuroanatomical level, ERP recordings have shown differential activation across grouping types, such that activation extends to the medial occipital and parietal cortex or the occipitotemporal areas for grouping by proximity or by shape similarity respectively (Han, Song, Ding, Yund & Woods, 2001). fMRI studies have also shown differentiation between grouping by orientation and collinearity in early visual areas (Altmann et al. 2003; Kourtzi, Tolias, Altmann, Augath, Logothetis, 2003).

Perceptual grouping is a low-level, pre-attentive function (e.g. Treisman, 1982; Gillam, 2001). Evidence suggests that the effects of perceptual grouping have a downstream influence on many visuo-spatial functions. For example, when asked to determine whether an item is above or below another item, response times are faster for objects that belong to the same perceptual group than for items from different perceptual groups (Hommel, Hehrke, & Knuf, 2000). Counting performance is also influenced by perceptual grouping; children find it easier to individuate items for counting when they can be differentiated, as opposed to when they can be grouped together by a property such as shape or size (Towse & Hitch, 1996).

Enns and Girgus (1985) investigated the influence of perceptual grouping and how this changes with development. Children aged 6, 8, 10 and 12 years, and adults were asked to estimate the distance between two elements that either belonged to the same or different perceptual groups. They found that estimated distances between items belonging to the same perceptual groups were smaller than estimated distances between items belonging to different perceptual groups. This distortion effect reduced with age. Thus, it appears that children are better able to inhibit the effects of perceptual grouping with increasing age. Indeed, Enns, Burack, Iarocci, Randolph (2000) attribute the pattern of performance in Enns & Girgus (1985) to a developmental change in the ability to attend appropriately to the demands of the task.

It is now understood that multiple factors influence the relative weightings of local and global (including perceptual grouping) processing (see Kimchi, 1992) and that perceptual organisation involves a number of independent processes, each with different developmental trajectories and attentional demands (e.g. Enns, Burack, Iarocci, Randolph, 2000; Kimchi, Hadad, Behrmann, Palmer, 2005; Porporino, Shore, Iarocci, Burack, 2004). As such, it is possible that the influence of perceptual grouping on performance is dependent on the task demands. In the present study, task demands will be manipulated by using perception, drawing and construction tasks. Drawing and construction tasks are more complex than a perception task as they have additional requirements such as planning and motor demands (see van Sommers, 1989). Feeney and Stiles (1996) compared local and global processing in perception and drawing tasks. They showed that whole objects were segmented into parts in a similar way in both tasks. This suggests that visual perception influences performance regardless of task demands. Bouaziz and Magnan (2007) investigated construction and drawing performance. Their construction task had reduced planning and motor demands, relative to the drawing task. When all parts were equally salient, global processing was similar across drawing and construction tasks. In contrast, when the salience of object parts was manipulated, this disrupted global processing in children aged 4, 5, 6, 7 and 8 years on the construction task, but on a drawing task only disrupted the global processing of the younger children (4- and 5-year-olds). Thus, it appears that, in the drawing task, the older children focused their attention on the additional demands associated with drawing the stimulus, whereas the younger children focused more on the visual properties of the stimulus. In contrast, on the construction task, all participants focused on the visual properties of the stimulus. Thus, in some circumstances, competing task demands reduce the attention given to visual perception.

Research into the distorting influence of perceptual grouping to-date, relates solely to perceptual judgments. In this study, we aim to not only investigate the effect of perceptual grouping on perception tasks, but to investigate the influence of perception grouping on drawing and construction tasks, and to track this developmentally. The tasks are based on Enns and Girgus' (1985) distance estimate task, and involve four types of perceptual grouping. The stimuli in the present study are more sensitive to developmental progression than those employed by Bouaziz and Magnan (2007) as perceptual grouping enables one to measure the extent to which global processing influences performance. As perceptual grouping affects the salience of parts of the image, it is possible that the effect of perceptual grouping across the three tasks will vary dependent on the weighting of the visual properties of the stimuli. This should reduce according to task demands, with the strongest influence on the perceptual task, followed by the construction task, then the drawing task. Importantly, the effect of perceptual grouping is predicted to reduce with increasing age for all three tasks, although the rate of development might differ across tasks.

Experiment 1

Method

Participants

Five groups of typically developing children, recruited from local primary schools in Berkshire, aged approximately 4, 5, 6, 7, and 8 years took part. A sixth typically developing group consisted of adults, recruited from the University of Reading. There were ten individuals in each group. The level of visuo-spatial ability of all participants was assessed using the Ravens Coloured Progressive Matrices (RCPM; Raven, 1993), a recognised non-verbal measure of fluid intelligence (Woliver & Sacks, 1986).

Table 1 about here

Design and Procedure

Stimuli: The same stimulus set was used for the perception, drawing and construction tasks. Each stimulus consisted of a row of four local elements, 10mm in diameter, two of which were the target pair. For control trials, four black circles were presented. For perceptual grouping trials, the local elements could be grouped by one of four gestalt grouping principles, as shown in Figure 1; shape similarity (black circles, black squares), luminance similarity (black circles, white circles), orientation similarity (black 10mm vertical lines, black 10mm lines at 30° anticlockwise from vertical) or proximity (black circles). In addition to perceptual grouping type, stimuli differed according to three other variables. These were: the position of the target pair (central or right); the grouping of the target pair (interior: elements belong to the same perceptual group or exterior: elements belong to different perceptual groups) and the distance between the target elements (40mm or 60mm).

With the exception of grouping by proximity, all elements were equally spaced by either 40mm or 60mm. For grouping by proximity, when target distances were exterior, the ratio of interior to exterior distances was 1:4. When target distances were interior, the presentation area did not allow this and a ratio of 1:2 was employed.

Trials: for each task, perception, drawing and construction, there were four practise trials and 18 experimental trials. For practice trials participants experienced one trial of each grouping type, whilst also allowing two demonstrations of each target position, target pair grouping and distance. Experimental trials were blocked into four trials of each grouping type, with trials within a block presented in a pseudo random order. Each combination of distance (40mm, 60mm) and target pair grouping (interior, exterior) was employed across each set of four trials. Target pairs were central (50%) or right (50%) for each set of four trials, counterbalanced across the other variables. The two control trials were interspersed between perceptual grouping blocks. These were: central target, 40mm distance; right target, 60mm distance.

Perception task: (adapted from Enns & Girgus, 1985): participants were presented with an A3 folder (portrait orientation). For each trial, the stimulus, as described above, was on the page on the right, and a set of corresponding response choices was on the page on the left. For each trial, the experimenter pointed to the target pair, i.e. the two central or two right-hand local elements of the stimulus. The participant was then asked to indicate which pair of elements on the response choice page was separated by the same distance as the target pair. Response choices were a series of graded pairs of elements and were the same shapes as the target pair on that trial (see Figure 2). For example, if the target pair consisted of a circle and a square, the response pairs also each consisted of a circle and a square. In each trial, participants could choose from 23 element pairs. These were horizontally spaced by between 28mm and 72mm, at 2mm increments. The vertical distance between element pairs was 8mm. To facilitate the ability to isolate pairs of response stimuli, participants were given a ‘viewing window’ This was a piece of white card (55mm by 180mm) with a cut-out ‘window’ measuring 150mm by 15mm such that participants could isolate each response pair by viewing it through the ‘window’.

For the practice trials, after the participant had responded, the experimenter gave feedback by demonstrating the correct response choice pair, by placing a transparency of the target pair over it.

Construction task: Participants were presented with the stimulus set only (no response choice pairs). These were the same stimuli as in the perception task, but were shown in an A4 folder (landscape presentation). For each trial, the experimenter indicated the target pair and participants were given a 3D model of the target pair, fixed to a plastic base (28mm by 140mm). One of the 3D target pair was fixed (placed vertically central, and horizontally 20mm from the edge), while the other was fixed vertically, but could be moved horizontally along a groove in the plastic base. Participants were asked to adjust the moveable element so that it was at the correct distance from the fixed element, to match the target pair in the stimulus pattern. In the practice trials, after the participant had responded, feedback was given by the experimenter adjusting the distance to the correct distance.

Drawing task: The same A4 folder of stimulus trials was presented as in the construction task. Participants were given a drawing booklet (28mm by 140mm). On each page of the booklet, one of the target pair was printed (vertically central, and horizontally 20mm from the edge). For each trial, the experimenter indicated the target pair of the stimulus pattern (in the A4 folder). The participant viewed the correct page in the drawing booklet, where one of the target pair was printed, and was asked to reproduce the target pair by drawing the remaining element at the correct horizontal distance from the printed element. To facilitate vertical alignment of the printed and drawn element, the dimensions of the drawing booklet were equivalent to the plastic base employed in the construction task. Feedback was given in the practise trials using transparencies, as in the perception task.

Figures 1 and 2 about here

Results

One child in the 4-year-old group failed to complete the perception task and so their data was excluded from the analyses.

Control trials

Performance on the control trials was analysed to determine baseline performance across tasks. ANOVA was carried out, with a within participant factor of task (perception, drawing, construction) and a between participant factor of age (4, 5, 6, 7, 8 years and adults). This showed a significant main effect of task. $F(2, 106)=9.73$, $p<.001$, partial $\eta^2 =.16$. This was because distance estimates for the drawing task were lower than for the perception and the construction tasks ($p<.05$ for both). Distance estimates changed with age ($F(5, 53) = 3.23$, $p=.01$, partial $\eta^2 =.23$; Tukey comparison: 8-year-olds < 4-year-olds, $p=.02$), but the effect of task remained consistent across age groups ($F<1$).

Experimental trials

ANOVA was carried out on experimental trials, with three within-participant factors of task (perception, drawing, construction), grouping type (shape similarity, luminance similarity, proximity, orientation) and distance type (interior, exterior) and one between participant factor of age (4, 5, 6, 7, 8 years and adult). There was a significant main effect of task, $F(2, 106)=19.89$, $p<.001$, partial $\eta^2 =.27$. This pattern is similar to the pattern observed for control trials; distance estimates were smaller for the drawing task than for the perception and construction tasks, and in addition distance estimates were smaller for the perception task than for the construction task ($p<.05$ for all). There was no main effect of grouping type, $F<1$. Interior distances were significantly lower than exterior distances, $F(1, 53)=12.55$, $p=.001$, partial $\eta^2=.19$. There was also a main effect of group, $F(1, 53)=3.50$, $p=.01$, partial $\eta^2=.25$. Post-hoc Tukey HSD analysis showed that this was due to lower distance estimates for the 8-year-olds compared to the 4- and 5-year old groups only ($p<.05$ for both). The most interesting interaction was between grouping type and distance type, $F(3, 159)=18.59$, $p<.001$, partial $\eta^2=.26$, as shown in Figure 3. The effect of distance type was significant for all grouping types, however, while this was due to smaller interior than exterior distance types for grouping by shape, proximity and orientation ($p<.05$ for all), for grouping by luminance interior distances were significantly *greater* than exterior distances ($p<.05$). However, this interaction also interacted with age and with task and with task by age (grouping type by distance type by age, $F(3, 159)=18.59$, $p<.001$, partial $\eta^2 =.39$; grouping type by distance type by task, $F(6, 318)=2.22$, $p=.04$, partial η^2 =.04; grouping type by distance type by task by age, $F(30, 318)=2.80$, $p<.001$, partial η^2 =.21). Analysis of each task separately revealed that the above interaction was driven by performance in the perception and drawing tasks, and that the interaction between distance estimate and grouping type for the construction task was due to an effect of distance estimate for proximity grouping only ($p<.001$). Further interactions are best described by separate analyses of each grouping type. Grouping by proximity showed the most consistent effect as the effect of distance type did not interact with age or task. For grouping by shape similarity, the effect of distance type was consistent across tasks, but was not consistent with age group (distance type by age group: $p<.05$); it was driven by the adult group ($p=.04$), with marginal effects from the 4-year-olds ($p=.06$) and 8-year-olds ($p=.07$). For grouping by orientation, the effect of distance estimate was observed for some age groups in the perception and drawing tasks, but not at all in the construction task (distance type by age and distance type by task by age, $p<.05$ for both). That is, for the perception task, the effect of distance type was driven by the 4-year-olds ($p<.001$) and the adults ($p=.001$) and marginally by the 6-year-olds ($p=.07$) and for the drawing task, the effect of distance type was driven by the 4-year-olds ($p<.01$) and marginally for the 8-year-olds ($p=.095$) and the adults ($p=.07$). For grouping by luminance, the effect of distance estimate, this time in the opposite direction (interior > exterior distances), was observed in the perception and drawing tasks, but not the construction task (distance type by age and distance type by task by age, $p<.05$ for both). That is, for the perception task the effect of distance type was driven by the 4-year-olds ($p=.003$) and for the drawing task the effect of distance type was driven by the 5-year-olds ($p=.014$) and the adults ($p=.03$), with a marginal effect at 7 years ($p=.099$).

Figure 3 about here

Discussion

Consistent with Enns and Girgus (1985), interior distance estimates were generally smaller than exterior distance estimates. Overall, this effect reduced from 4- and 5-years to 8-years. This is consistent with Enns and Girgus (1985), who captured a slightly different portion of the trajectory (6, 8, 10 and 12 years, and adults), but also observed a reduction in distortion with age. In the present study, adult performance did not strictly follow this developmental trend, as distance estimates were never significantly different from any of the groups of children. It appears that any changes in distortion effects between children and adults were not powerful enough to be captured here. Thus, we can only partially support our hypothesis that the influence of perceptual grouping reduces with age.

We also hypothesised that the effect of perceptual grouping would differ according to task demands. This was borne out in part, as the pattern of distance estimates observed in the perception and drawing tasks differed from the pattern observed in the construction task. In the perception and drawing tasks, the effects of perceptual grouping were notable, which suggests that the visual properties of the stimuli strongly influenced performance. In the construction task, this was also true when items were grouped by proximity. However, when grouping was by shape, luminance or orientation, it appears that the visual properties of the stimulus influenced performance less, in relation to other task demands, such as manipulating the 3D object. The difference between the construction and perception task supports our hypothesis. However, given that the drawing task had motor demands, it is surprising that participants were more influenced by perceptual grouping on this task than on the construction task. This also contrasts to Bouaziz and Magnan (2007) who demonstrated more influence of visual properties in a construction task than in a drawing task. This suggests that the relationship between the influence of the visual properties of stimuli and other task demands is more complex than hypothesised or that perhaps, in this set of tasks, drawing the second item was less computationally demanding than manipulating a 3D item.

While the distorting effect of perceptual grouping was evident for all three tasks, overall distance estimates in the drawing task were underestimated, and tended to be overestimated in the construction task. The additional bias was observed in control and experimental trials, which demonstrates that, on experimental trials, the effect was independent of any influence of perceptual grouping. The drawing and construction tasks differ from the perception task, in that participants had to estimate the location of one object, relative to the fixed location of a given object. This requirement to use the fixed object as a reference point or landmark appears to be the source of the additional distorting effects on these tasks.

Schmidt et al. (2003) report that, when asked to estimate the location of a target dot relative to an unfilled circle on a black background with no distinct edges, estimations were biased towards the circle. In the drawing task used here, the printed stimulus was presented on a 2D piece of white paper. Given that the edges of the paper were not salient relative to the printed stimulus, we suggest that the printed stimulus acted as a landmark and that drawings of the second stimulus were biased towards it, resulting in an overall bias to underestimate distances.

In the construction task, the plastic base was 3D. The edges and stimuli were also all connected by a visible horizontal groove. We suggest that these two factors increased the salience of the edges. Nelson and Chaiklin (1980) demonstrated that, when the spatial array has a distinct edge, location estimates are biased towards it. This could explain the overestimated distances on this task. We also suggest that participants coded the distance between each stimulus and the nearest edge. The distance between the stimulus and the nearest edge was necessarily shorter for the fixed stimulus (20mm) than for the moveable stimulus (60mm when 60mm from the fixed stimulus or 80mm when 40mm from the fixed stimulus). This was so that both underestimates and overestimates were equally possible for the moveable stimulus, but it also introduced asymmetry. As symmetry relates to Gestalt ‘goodness’ or ‘pragnantz’ (Kubovy, Holcombe & Wagemans, 1998; Wagemans, 1997), and also the four stimuli presented in the test booklet (two target and two non-target, see Figure 1) were symmetrically aligned, participants might have been biased towards symmetry. Indeed, Feldman (2000) demonstrated a similar effect; his participants drew triangular and quadrilateral shapes as more symmetrical than an example, non-symmetrical shape. In the construction task here, a bias which relates, first to the salience of the edges, which acted as reference points (Nelson & Chaiklin, 1980), and second to a bias towards symmetry (Feldman, 2000), can explain the overall bias to overestimate distance estimates.

The extent of the distortion brought about by *perceptual grouping* (exterior minus interior distance estimates) differed according to perceptual grouping type. This was due to a striking effect of perceptual grouping for grouping by luminance, in which the pattern of performance was incongruous compared to other grouping types; interior distance estimates were *greater* than exterior distance estimates. Grouping by luminance and by proximity were also employed by Enns and Girgus (1985), yet they did not observe a similar differentiation across grouping types (exterior distances were consistently larger than interior distances). This could relate to differences in the stimuli employed. For grouping by luminance, Enns and Girgus only used pairs of black circles as interior stimuli, whilst we employed pairs of black circles and pairs of white circles equally. Thus, the results of the present study provide a more comprehensive representation of the effects of grouping by luminance. Luminance is thought to be the most robust type of grouping ability (see Quinn & Bhatt, 2006), and has been shown to be present in neonates (Farroni et al., 2000), while other types of grouping emerge later (e.g. Quinn & Bhatt, 2005). Although this differentiates grouping by luminance from other forms of grouping, it does not explain the pattern of performance observed here. It appears that, rather than perceptually attracting stimuli together, luminance similarity perceptually repels stimuli from one another. Perhaps this relates to inhibition. In Enns & Girgus (1985) participants were less affected by perceptual grouping with increasing age as they were better able to inhibit the distorting effects. If participants in this study were overinhibiting the effects of grouping by luminance, this might result in the pattern observed. This effect does not, however, reduce with age; smaller exterior than interior estimates were observed at 4 years and 5 years, but also in the adult group.

In summary, perceptual grouping has a distorting effect across three types of tasks, throughout development. Grouping by proximity had the most consistent effect on performance across tasks and age groups. This is consistent with previous research which demonstrates a relative strength in perceptual grouping by proximity compared to other forms of perceptual grouping (e.g. Kurylo, 1997). Furthermore, the ability to judge distances using drawing and construction is subject to location coding biases.

Experiment 2

The focus of Experiment 2 relates to perceptual grouping in atypical development. Individuals with disorders such as Autism Spectrum Disorder and Williams syndrome show strengths and weaknesses across different types of perceptual grouping (Brosnan, Fox, Scott & Pye, 2004; Farran, 2005; Farran, Brown, Cole, Houston-Price & Karmiloff-Smith, 2007). This provides further evidence for dissociated perceptual grouping mechanisms. This also suggests that the downstream effects of perceptual grouping on visuo-spatial processes such as spatial distance estimation, counting performance, and object recognition, might also be atypical in these populations. In this Experiment we examined the effects of atypical perceptual grouping abilities on distance estimates in Williams syndrome.

Williams syndrome (WS) is a rare genetic disorder, in which visuo-spatial cognition is markedly poorer than verbal cognition (e.g. Mervis, 1999). Furthermore, both the visuo-spatial and verbal domain show atypical patterns of strengths and weaknesses (Karmiloff-Smith, 1997; Farran & Jarrold, 2003). Performance on drawing and construction tasks is poor in WS and represents a relative weakness within the visuo-spatial domain (e.g. Bellugi, Sabo & Vaid, 1988; Hoffman, Landau & Pagini, 2003). The solutions offered by individuals with WS typically show attention to the local elements, but poor global cohesion. This contrasts to perceptual processing where no local bias is observed; individuals with WS can perceive stimuli at both the local and the global level (Farran, Jarrold & Gathercole, 2003). It is possible that poor drawing and construction performance relates to poor working memory performance in WS. A number of studies have shown weak visuo-spatial working memory in WS (e.g. Jarrold, Baddeley & Hewes, 1998a), and more specifically, a relative impairment in spatial working memory compared to visual working memory (Vicari, Bellucci & Carlisimo, 2003; 2006). These impairments might make it difficult to maintain an image of the model image in memory, while reproducing it.

Perception in WS has been further examined using perceptual grouping (Farran, 2005). Participants were presented with a matrix of local elements which could be perceptually grouped into columns or rows according to one of six gestalt principles and were asked to determine which direction, horizontal (rows) or vertical (columns), the elements were grouped. Individuals with WS behaved at the same level as a typically developing (TD) control group, matched by visuo-spatial ability, for grouping by luminance, closure, and alignment, but performed at a level lower than controls for grouping by shape, orientation and proximity. This suggests that, although global processing is available at the perceptual level in WS, it is atypical; it might be achieved by relying on relative strengths in perceptual grouping.

In their autopsy studies of WS brains, Galaburda and colleagues (Galaburda & Bellugi, 2000; Galaburda, Holinger, Bellugi, & Sherman, 2002) report that, despite a well-differentiated area V1, one of the areas activated by perceptual grouping in typical development, individual layers showed abnormalities (e.g. areas of increased cell packing, neuronal size differences), when compared to control brains. MRI studies report increased gyrification (cortical folding) in WS in the right parietal and occipital lobes (Schmitt et al., 2002), and a disproportionate reduction in parietal-occipital regions (Meyer-Lindenberg et al., 2004; Reiss et al., 2000; 2004). At a functional level, ERP investigation has shown that individuals with WS can group by closure, but that this is associated with deviant neural processing in the temporal-occipital areas (Grice et al., 2003). It appears then that atypical perceptual grouping in WS relates to neuroanatomical and functional abnormalities in the cortical circuits which are activated during perceptual grouping in the typical population.

Given that both perceptual grouping and drawing and construction abilities are atypical in WS, it is important to consider the relationship between these impairments. The cognitive demands of drawing and construction tasks dictate that the individual must correctly perceive an image, and then reproduce it part by part, until a cohesive production has been achieved. Whilst this requires working memory, this also requires knowledge of the manner in which each of the elements relates to one another. It is therefore possible that an atypical pattern of perceptual grouping, although not prohibitive to global processing at perception, has a detrimental impact on drawing and construction performance.

In Experiment 1, we observed that in typical development, perception, drawing and construction are all affected by perceptual grouping. In addition, drawing and construction were affected by a second bias, related to location coding. If individuals with WS show typical patterns of performance, one would expect similar biases to those observed in Experiment 1. However, given the uneven pattern of perceptual grouping ability in WS, and the relative deficit in construction and drawing, one would expect atypical patterns of distortion in this group. It is predicted that distance estimate biases will be observed for perceptual grouping abilities that are relatively strong in WS, but will be weak or not present for weaker perceptual grouping abilities. If drawing and construction performance is more influenced by perceptual grouping ability than perceptual abilities in WS, any differentiation across grouping types will be more pronounced in these tasks, than the perceptual task. Although, given that performance in typical development observed in Experiment 1 differentiated perception and drawing performance from construction, it is possible that for these particular tasks, the above hypothesis of a stronger influence of perceptual grouping might relate to the construction task only. Furthermore, we hypothesised that the relative underestimation and overestimation of distance estimates in the drawing and construction tasks respectively which occurred in Experiment 1 could be accounted for by biases in visual perception of locations, rather than additional task demands such as manual manipulation. As visual perception is atypical in WS (Farran, 2005), it is difficult to determine whether similar location coding biases will be observed in this atypical group. However, evidence to-date suggests atypical location coding in this population (e.g. Farran & Jarrold, 2005). Across all tasks, it is expected that the extent of bias will vary across grouping types in the WS group, relative to typical development.

Method

Participants

Twenty-three individuals with WS were recruited from the records of the Williams Syndrome Foundation, UK. All individuals had received positive diagnosis of WS based on phenotypic and genetic information. Genetic diagnosis was by a Fluorescent insitu Hybridisation (FISH) test. This checks for the deletion of elastin on the long arm of chromosome 7, which occurs in approximately 95% of individuals with WS (Lenhoff, Wang, Greenberg & Bellugi, 1997). The data from twenty-two typically developing individuals, who took part in Experiment 1, was used for analysis. These were matched individually to the WS group by RCPM score. Table 2 illustrates the RCPM raw scores, and chronological age (CA) of the WS and TD match groups. An independent t-test of RCPM score indicated that the groups were well matched, p=.92 (WS=TD).

Design and Procedure

The Design and Procedure were identical to Experiment 1

Table 2 about here

Results

One individual with WS failed to complete the perception task and so their data was excluded from the analyses.

Control trials

Performance on the control trials was analysed to determine baseline performance across tasks. ANOVA was carried out, with a within participant factor of task (perception, drawing, construction) and a between participant factor of group (WS, TD match). The main effect of task was significant, $F(2, 84)=6.88$, $p=.002$, partial =0.14. Similar to Experiment 1, this was due to shorter distance estimates for the drawing task compared to the perception and construction tasks ($p<.05$ for both comparisons). The main effect of group was not significant, $F<1$. There was no interaction between task and group, $F<1$.

Experimental trials

ANOVA of experimental trials was carried out with within participant factors of task (perception, drawing, construction), grouping type (proximity, luminance, shape, orientation), and distance type (interior, exterior) and a between participant factor of group (WS, TD match). There was a significant main effect of task, $F(2, 84)=14.98$, $p<.001$, partial $\eta^2=.26$. Similar to Experiment 1, and the control trials, this was due to smaller distance estimates for drawing compared to perception and construction tasks, and smaller estimates for perception than construction ($p<.05$ for all). The main effect of distance type was significant, $F(1, 42)=7.72$, $p=.01$, due to smaller interior than exterior distance estimates. The main effect of group was not significant, $F<1$. An interaction between grouping type and group ($F(3, 126)=3.38$, $p=.02$, partial $\eta^2=.08$), revealed that a main effect of grouping type ($F(3, 126)=3.88$, $p=.01$, partial $\eta^2=.09$) was driven by the WS group (effect of grouping type: WS: $F(3, 63)=7.11$, $p<.001$; TD: $F<1$). The WS group showed smaller distance estimates for grouping by luminance and shape than for grouping by orientation ($p<.05$ for both). Grouping type also interacted with distance type, $F(3, 126)=5.60$, $p=.001$, partial η^2

=.12. This was due to smaller interior than exterior distances for grouping by shape and proximity ($p<.05$). A similar, but non significant pattern for grouping by orientation ($p=.110$), but marginally *greater* interior than exterior distance estimates for grouping by luminance ($p=.084$). There was also a 3-way interaction between grouping type, distance type and group, $F(3, 126)=3.14$, $p=.03$, partial $\eta^2=.07$, as shown in Figure 4. This was due to differential interactions between grouping type and distance type for each group (WS: $F(3, 63)=3.49$, $p=.02$, partial $\eta^2=.14$; TD: $F(3, 63)=5.37$, $p=.002$, partial $\eta^2=.20$). For the WS group, this was driven by significantly lower interior than exterior distance for shape only ($p=.001$) and for the TD group, this was driven by proximity only ($p=.001$), as well as a marginal effect of luminance in the opposite direction (exterior <interior, $p=.098$). Despite this apparent group difference, analysis of each grouping type separately revealed a significant interaction between group and distance type for proximity only: ($F(1, 42)=4.10$, $p=.05$, partial $\eta^2=.09$ (all other grouping types, $p<.05$). All remaining interactions were not significant (grouping type by group by task: $F(6, 252)=1.05$, $p=.39$, partial $\eta^2=.02$; grouping type by group by task by distance type: $F<1$).

Figure 4 about here

Discussion

The results of this study show that individuals with WS demonstrate many of the biases in distance estimates observed in typical development. First, the WS group showed smaller interior distance estimates than exterior distance estimates, with the exception of grouping by luminance where the opposite pattern was observed. This pattern was evident in both the WS and TD match group, as also observed in Experiment 1. Second, distance estimates were underestimated in the drawing task and overestimated in the construction task, in both the WS and TD match group, as also observed in Experiment 1.

The results of Experiment 2, therefore, show that perceptual grouping can produce biases in distance judgements in WS, despite their atypical perceptual grouping abilities. In WS, therefore, there is a dissociation between the ability to explicitly determine a property of a perceptual group (i.e. whether the elements are grouped horizontally/ vertically; Farran, 2005), and the implicit, pre-attentive, influence that perceptual grouping has on performance. The former is at or below the level of a typical 6-year-old and show an atypical pattern of performance, but the latter demonstrated typical biases in performance, akin to that observed in typical children and adults. This suggests that, despite evidence for atypical neural processing of perceptual grouping in WS (Grice et al., 2003) and associated cortical abnormalities, the feedforward effects of perceptual grouping, at both cognitive and cortical levels, are similar to those observed in typical development. The structural differences in area V1 (Galaburda et al., 2002), parietal and occipital cortex (Meyer-Lindenberg et al., 2004; Reiss et al., 2000; 2004; Schmitt et al., 2002) in WS, which might account for poor performance in Farran (2005), do not influence pre-attentive perceptual grouping mechanisms, as observed in this study.

The second distortion effect, which was independent of the biases associated with perceptual grouping, biased distances to be underestimated and overestimated in the drawing and construction tasks respectively. As suggested in Experiment 1, this can be accounted for by participants using the fixed object in these tasks as a reference point or landmark. That is, the printed stimulus acted as a landmark in the drawing task, and the edge of the plastic base acted as a landmark in the construction task. The finding that this pattern of performance in the WS group did not differ from typical development demonstrates that, for some aspects of location coding, typical strategies are employed in WS. These results contrast to Farran and Jarrold (2005), where individuals with WS demonstrated atypical biases. Farran and Jarrold (2005) trained participants to classify locations based on categorical (whether a ball is above or below a horizontal bat) or coordinate (whether a ball is within or beyond a particular, unmarked, distance from the bat) spatial relations (see Kosslyn & Koenig, 1992). The current tasks involve the precise distance between two locations, i.e. coordinate relations. In comparison to the coordinate relations task employed by Farran and Jarrold (2005; adapted from Koenig, Reiss & Kosslyn, 1990), the current study provides a more sensitive measure of coordinate relations, as no categories are imposed. It appears then, that individuals with WS can code the coordinate relations between pairs of locations in a typical manner, but show atypical performance when locations are classified according to spatial categories (also see, Farran, in press).

The unexpected effect of perceptual grouping, observed in Experiment 1, in which the pattern of performance for grouping by luminance was consistently incongruous compared to other grouping types, was also observed in Experiment 2. In Experiment 1, we presented a hypothesis that this effect can be explained by inhibition, i.e. that participants were overinhibiting the effects of grouping by luminance. If this hypothesis is true, then the incongruous effect for grouping by luminance observed in WS, shows consistency to the pattern of performance for grouping by luminance in typical development. This adds further support for typical down-stream effects of perceptual grouping in WS and to the notion that grouping by luminance is a relatively robust form of grouping in WS.

The performance of the WS group differed from typical development across perceptual grouping types. Distance estimates showed similar errors overall (collapsed across distance estimate type and across task), for each perceptual grouping type in the TD matched group, but showed an uneven profile in the WS group. Analysis revealed that the WS group produced particularly underestimated distances for grouping by shape and luminance. This effect did not interact with task and so is not driven by the underestimations observed in the drawing task. We suggest two independent reasons for underestimated shape and luminance distance estimates. For grouping by luminance, both exterior and interior distances, when considered across tasks, were generally underestimated in WS. This relates to the incongruent effect of grouping by luminance, such that exterior distances were underestimated to a greater extent than interior distances. For grouping by shape, the effect is driven by underestimated interior distances and is illustrated further by a three way interaction between group, grouping type and distance estimate type where the WS group demonstrate a strong distortion effect (exterior minus interior distances) for grouping by shape. Thus, it appears that the effects of grouping by shape similarity are particularly strong in WS, specifically on account of underestimated interior distance estimates.

We hypothesised in this study, that the extent of the distorting influence of perceptual grouping (exterior minus interior distance estimates) would be uneven across perceptual grouping types in WS, relative to typical development. This was based on the uneven pattern of perceptual grouping judgement abilities (Farran, 2005). If this prediction were borne out, then the distorting influence of grouping by shape, orientation and proximity should have been weaker than the TD match group, and the distorting influence for grouping by luminance at a similar level to the TD match group. Our hypothesis was supported in part: the distorting effect of perceptual grouping differed between the WS and TD match groups. However, the predicted pattern was not observed. The WS group showed a distorting effect for grouping by shape, which was not significantly evident in the TD match group (although, note that this was evident as a group difference), while the TD match group showed a distorting effect for grouping by proximity, which was not significantly evident in the WS group. Interestingly, as noted in the discussion of Experiment 1, the effect for the TD match group shows consistency with previous research in which a relative strength in perceptual grouping by proximity is reported (e.g. Kurylo, 1997). The incongruence in the pattern of perceptual grouping abilities in WS in this study compared to Farran (2005) provides further evidence for a differentiation between the ability to make attentive judgements relating to perceptual grouping measured by Farran (2005), and the pre-attentive effects that perceptual grouping can have on other visuo-spatial judgement tasks in WS, observed here.

Our second hypothesis related to the reported differences between performance on perception tasks, relative to performance on drawing and construction tasks in WS (e.g. Farran et al., 2001; 2003). We hypothesised that, if poor drawing and construction abilities related to the unusual pattern of perceptual grouping abilities in WS, that any observed biases in the distance estimates of the WS group in this study, will be exaggerated in the drawing and construction tasks, relative to the perception task. This was not observed; the extent of the distorting effects of perceptual grouping on WS performance, did not differ across tasks, and was comparable to typical development for all three tasks. This suggests that a poor ability to determine perceptual groups cannot explain the relative weakness in drawing and construction in WS. This finding, therefore, paves the way for further research into other potential factors which might explain this specific deficit in the WS cognitive profile. Potential factors include: poor planning abilities, impaired mental imagery

(Farran, Jarrold & Gathercole, 2003; Farran & Jarrold, 2004; Vicari et al., 2006) and working memory abilities (Jarrold et al., 1998; Vicari et al, 2003; 2006) and a deficit in the ability to use visual feedback.

General Discussion

Perceptual grouping has a distorting effect on performance across three types of tasks, perception, drawing and construction, despite differences in task demands. Interestingly, the distorting influence for grouping by luminance is in the opposite direction to the bias observed for grouping by proximity, shape and orientation. This pattern was not predicted, but was consistent across Experiments 1 and 2, and could relate to a relative overinhibition of the effects of grouping by luminance, compared to other grouping types. Furthermore, the ability to judge distances using drawing and construction is subject to location coding biases. This appears to relate to the use of landmarks when coding distance.

Interestingly, the above distortion effects were consistently observed across typical development and WS. Contrary to our hypotheses in relation to WS (Experiment 2), first, the pre-attentive influence of perceptual grouping did not correspond to the unusual ability to attend to perceptual grouping in WS. Second, the differentiation between performance on the construction and drawing tasks relative to the perception task, was not atypical in WS. WS performance differed from typical development in two ways. First, averaged across tasks, the profile of the distance estimate error for each type of perceptual grouping was atypical. Second, the distorting effect of perceptual grouping (exterior minus interior distances) differed in the WS group compared to the TD group according to grouping type.

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Table 1: Experiment 1 Participant Details showing CA and RCPM scores for each TD group.

Group	CA (years; months): mean(SD)	RCPM score: mean(SD)
TD: 4-year-olds	4;7 (0;3)	12.30(2.91)
TD: 5-year-olds	5;3(0;3)	16.20 (5.07)
TD: 6-year-olds	6;6(0;3)	22.30(3.97)
TD: 7-year-olds	7;8(0;4)	26.40(3.50)
TD: 8-year-olds	8;5(0;4)	29.00(4.78)
TD: adults	24;7 (5;0)	34.70 (1.95)

Table 2: Experiment 2 Participant details showing CA and RCPM scores.

Group	CA (years; months): mean(SD)	RCPM score: mean(SD)
WS	23;2 (8;11)	19.56 (7.14)
TD match	6;6 (1;7)	20.14 (7.12)

Figure Captions

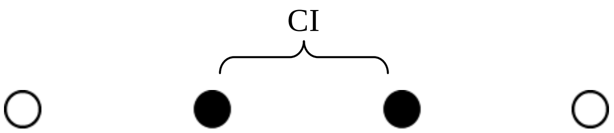
Figure 1: Example stimulus patterns

Figure 2: Example response stimuli, used in perception task only

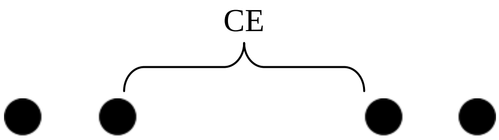
Figure 3: Mean perceptual grouping distortion (exterior minus interior distance estimates) for TD groups, averaged across perception, drawing and construction tasks.

Figure 4: Mean perceptual grouping distortion (exterior minus interior distance estimates) for the WS and TD match groups, averaged across perception, drawing and construction tasks.

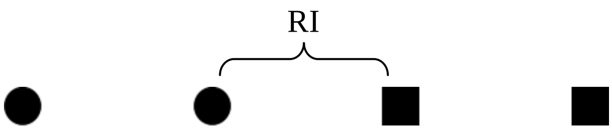
Figure 1



Luminance with centre interior (CI) target pair illustrated (40mm distance)

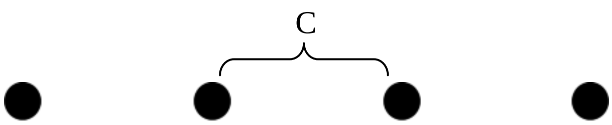


Proximity with centre exterior (CE) target pair illustrated (60mm distance)



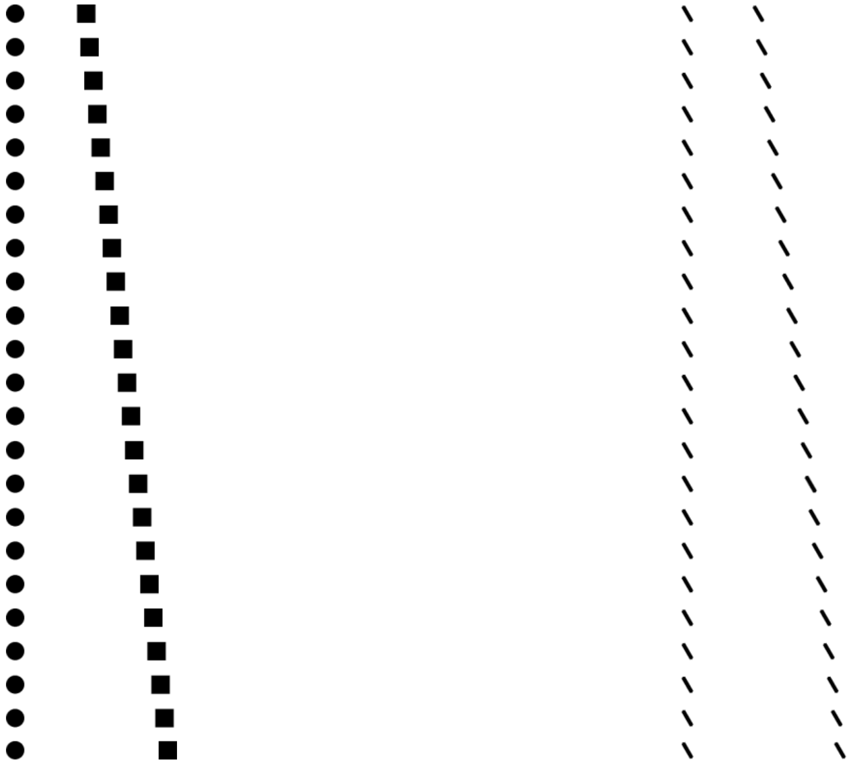
Shape with right interior (RI) target pair illustrated (40mm distance)

Orientation with right exterior (RE) target pair illustrated (60mm distance)



Control with central (C) target pair illustrated (40mm distance)

Figure 2



Shape, exterior distances

Orientation, interior distances

Figure 3

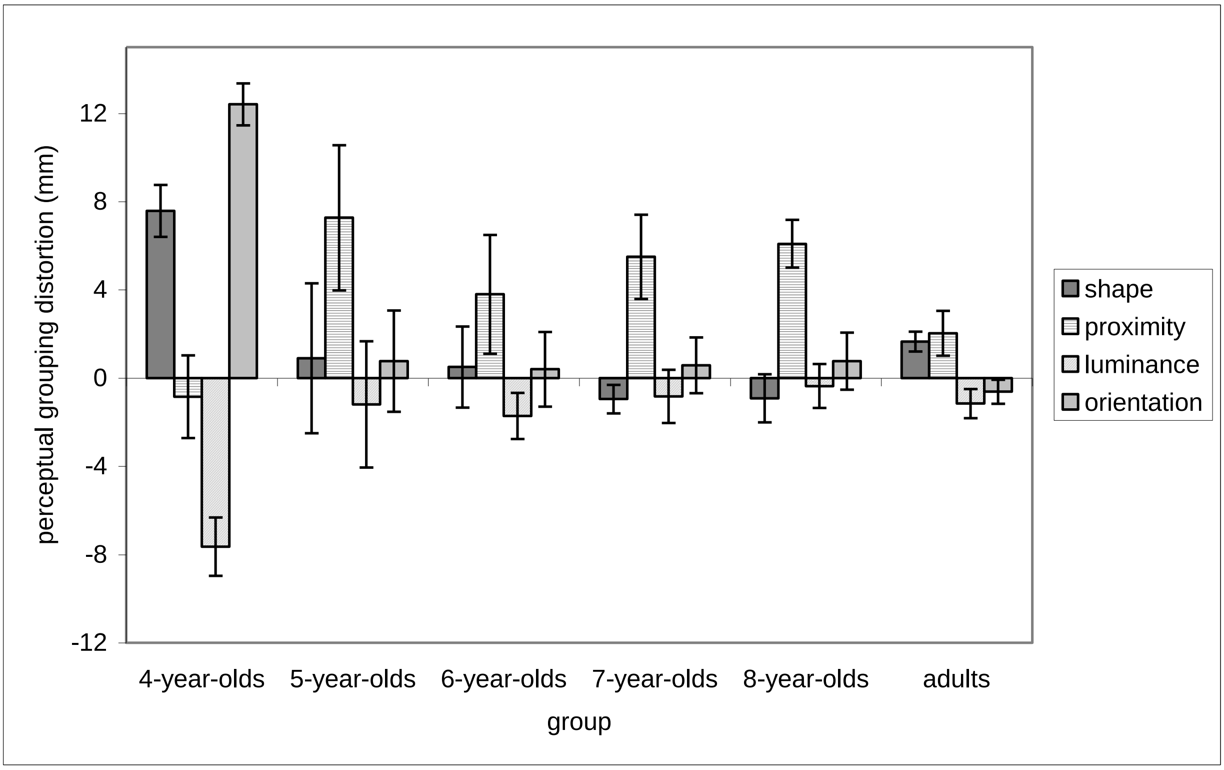
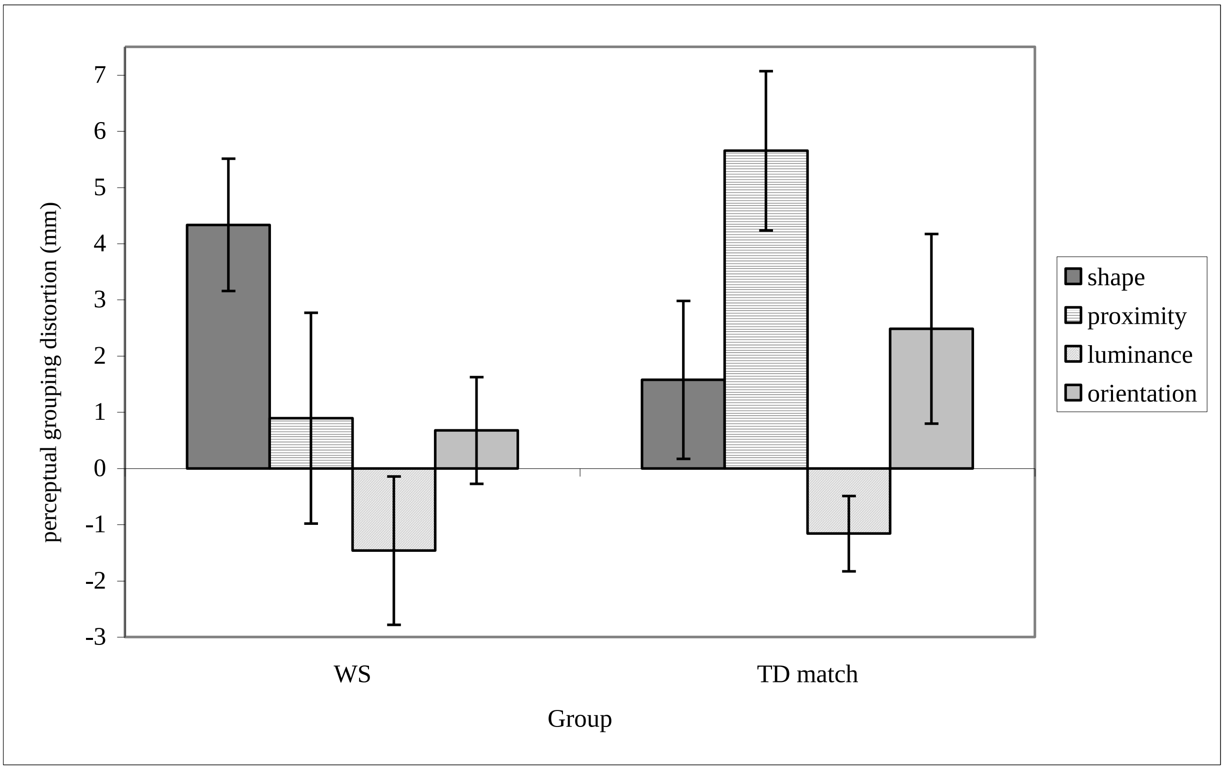

perceptual grouping distortion (mm)
12
8
4
0
-4
-8
-12
4-year-olds
5-year-olds
6-year-olds
7-year-olds
8-year-olds
adults
group
shape
proximity
luminance
orientation

Figure 4


7
6
5
4
3
2
1
0
-1
-2
-3
perceptual grouping distortion (mm)
WS
TD match
Group
shape
proximity
luminance
orientation