RUNNING HEAD: Texture segmentation and Williams syndrome

Texture Segmentation in Williams Syndrome

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Abstract

Williams syndrome (WS) is a developmental disorder in which visuo-spatial cognition is poor relative to verbal ability. At the level of visuo-spatial perception, individuals with WS can perceive both the local and global aspects of an image. However, the manner in which local elements are *integrated* into a global whole is atypical, with relative strengths in integration by luminance, closure, and alignment compared to shape, orientation and proximity. The present study investigated the manner in which global images are *segmented* into local parts. Segmentation by seven gestalt principles was investigated: proximity, shape, luminance, orientation, closure, size (and alignment: Experiment 1 only). Participants were presented with uniform texture squares and asked to detect the presence of a discrepant patch (Experiment 1) or to identify the form of a discrepant patch as a capital E or H (Experiment 2). In Experiment 1 the pattern and level of performance of the WS group did not differ from that of typically developing controls, and was commensurate with the general level of non-verbal ability observed in WS. These results were replicated in Experiment 2, with the exception of segmentation by proximity, where individuals with WS demonstrated superior performance relative to the remaining segmentation types. Overall, the results suggest that, despite some atypical aspects of visuo-spatial perception in WS, the ability to segment a global form into parts is broadly typical in this population. In turn, this informs predictions of brain function in WS, particularly areas V1 and V4.

Texture Segmentation in Williams Syndrome.

Introduction

Individuals with Williams syndrome (WS) show impaired visuo-spatial cognition relative to verbal performance (e.g. Udwin & Yule, 1991). Furthermore, some aspects of visuo-spatial performance in WS are poorer than others. Arguably the most impaired performance is observed on production tasks, i.e. visuo-spatial construction and drawing tasks (Bellugi, Sabo & Vaid, 1988; Mervis, Morris, Bertrand & Robinson, 1999). Performance on such tasks is characterised by a lack of global organisation: individual elements are not integrated accurately into the global form (e.g. Bellugi et al., 1988).

It was first hypothesised that individuals with WS have a global impairment/local bias across all areas of visuo-spatial cognition (Bellugi et al., 1988). It is now recognised that this cannot be supported: at the level of perception, both local and global processing are available to individuals with WS. Farran, Jarrold & Gathercole (2003) demonstrated this using the Navon hierarchical processing task (Navon, 1977). In a drawing version of the task, individuals with WS showed significantly poorer global than local accuracy, which compared to equal levels of local and global accuracy in the typically developing (TD) control children (matched for level of visuo-spatial cognition). In contrast, on two perceptual identification tasks, individuals with WS were able to process both the local and the global levels of Navon figures in a similar manner to controls.

Farran (2005) explored global and local perception further by investigating perceptual integration across seven gestalt principles of perceptual organisation (see Koffka, 1935; Wertheimer, 1923). Participants were presented with a matrix of local elements and asked whether these elements were perceptually grouped horizontally or vertically. Results showed that grouping ability was not uniform across grouping types in WS. The performance of individuals with WS was at the same level as a control group matched by non-verbal ability when grouping by luminance, closure, and alignment. However, their ability to group by shape, orientation and proximity was significantly poorer than controls. This suggests that although global processing is available to individuals with WS, it may not be accomplished in a typical manner: the ability to integrate local elements into a global form varies according to the perceptual grouping principles involved.

Given that perceptual integration in WS displays an atypical profile, the present Experiments consider segmentation ability in WS. Integration and segmentation can be thought of as opposing processes. That is, integration refers to the grouping of local elements into a global form according to the similarities or *associations* among those elements, whilst segmentation refers to the separation of parts from a global scene according to *dissociations* between the local elements of the scene (e.g. Kohler, 1929). Both of these processes are preattentive and are thought to function to form objects for object recognition, to direct attention, and to increase the efficiency of higher level processing (see Gillam, 2001).

Reiss, Hoffman & Landau (2005) discuss segmentation difficulty as a possible reason for differences in performance on three motion processing tasks in WS. WS performance was similar to typically developing adults in a motion coherence and biological motion task, both of which required participants to discriminate coherent motion (the gestalt principle of common fate) from random motion. In contrast, in a form-from-motion task, WS performance did not exceed the level of a typically developing 6-year-old. This task differed from the other two motion tasks as it involved segmenting a target from the background, both of which displayed coherent motion. Reiss et al. (2005) suggest that these segmentation demands could account for the poor performance in WS on this task.

Atkinson et al. (2003) employed motion and form coherence tasks to further assess their hypothesis that individuals with WS display a deficit in dorsal relative to ventral stream processing (see Atkinson et al., 1997). Their motion coherence task was similar to Reiss et al.'s (2005) form-from-motion task. The form coherence task involved indicating whether a proportion of line segments grouped by the principle of good form, was displayed left or right of centre. Results showed that children with WS performed at the level of typically developing 5-year-olds and that form and motion coherence performance did not differ significantly. However, a subset of WS children demonstrated higher form than motion coherence ability. Atkinson et al. (2003) explained that this could reflect immature dorsal relative to ventral stream development, akin to typical development between 4 and 5 years. A recent comparable study showed that WS adults (Atkinson et al., 2006) also demonstrate poorer motion coherence than form coherence. These findings support a dorsal stream deficit in WS. However, Atkinson and colleagues recognise that this is not specific to WS. A dorsal stream 'vulnerability' is observed in other developmental disorders, whose visuo-spatial profile is different from that observed in WS (Braddick et al., 2003).

The present study does not aim to inform the dorsal stream deficit hypothesis. The studies above, however, provide a useful insight into perceptual segmentation in WS, albeit according to two gestalt principles, good form and common fate. Segmentation performance appears to be generally poor, but no more so than previous reports of visuo-spatial cognition in WS (see Farran & Jarrold, 2003). Interestingly, similar to perceptual integration (Farran, 2005), WS performance across two gestalt principles appears to suggest that the profile of segmentation abilities may not be uniform (Atkinson et al., 2003, 2006).

The current study investigated segmentation ability in WS. Segmentation is typically investigated using texture. Individuals are presented with a square of texture, which displays a discrepant patch caused by a change in the local elements of the texture. Typically the individual is asked to determine whether there is a discrepant patch (e.g. Kimchi & Navon, 2000), or to identify the location/identity of a discrepant patch (e.g. Nothdurft, 1985, 1991).

In typical development, forms of texture segmentation can be differentiated developmentally: the ability to segment by common fate and size are available at 8-weeks, whilst segmentation by orientation becomes available later, at 10-weeks (Reith & Sireteanu, 1994; Sireteanu & Reith, 1992). This suggests that texture segmentation is not a unitary process, but that segmentation by different gestalt principles operates as separate mechanisms.

At a cortical level, texture segmentation starts at early visual areas. Evidence has been shown for higher activation of area V1 for a figure defined by texture boundaries than to elements belonging to the background (Lamme, 1995). V1 and V2 have also shown activation to the contours of stimuli (e.g. Grosof et al., 1993). Neuroanatomical investigation of individuals with WS supports the idea that texture segmentation may be impaired. Galaburda and Bellugi (2000) report autopsies of 4 WS brains, finding a well-differentiated area V1. However, the layers of V1 showed abnormalities, this included areas of increased cell packing and neuronal size differences in WS brains, compared to control brains (Galaburda, Holinger, Bellugi, & Sherman, 2002).

Beyond area V1, in the typical population, extrastriate areas V4 and TEO show increased activation where texture segmentation is determined by orientation disparity (Kastner et al., 2000) whilst a portion of area V4 activates when luminance defines texture boundaries (Pasupathy & Connor, 2001). It is difficult to relate this to cortical function in WS as there are no reported investigations of these specific extrastriate visual areas. The results of the present Experiments, will therefore inform hypotheses relating to possible neuroanatomical atypicalities in WS.

Given that the balance of local and global processing is typical (Farran et al., 2003), yet integration (perceptual grouping) is unusual in WS (Farran, 2005), segmentation merits examination. We are interested in whether the profile of perceptual grouping abilities observed in WS is mirrored in their segmentation abilities or whether it is particular to integration only. Texture segmentation will be investigated in Experiment 1 across seven different gestalt principles. These are the 6 principles employed by Farran (2005) as well as an additional form of segmentation by similarity, namely size similarity. This was included due to reports of reduced sensitivity to size in toddlers with WS (Scerif, Cornish, Wilding, Driver & Karmiloff-Smith, 2004).

Experiment 1

Method

Participants

Twenty individuals with WS took part in Experiment 1. WS participants were recruited from the records of the Williams Syndrome Foundation, UK. All individuals had received a positive genetic diagnosis for WS. Diagnosis was by a Fluorescent in-situ Hybridisation (FISH) test, which checks for the deletion of elastin on the long arm of chromosome 7. Elastin is one of the twenty-four genes typically deleted in WS (Tassabehji, 2003) and is deleted in approximately 95% of individuals with WS (Lenhoff, Wang, Greenberg & Bellugi, 1997). All twenty individuals had also been diagnosed phenotypically by a clinician. The individuals with WS were matched individually to twenty typically developing (TD) children by their score on the Ravens Coloured Progressive Matrices (RCPM; Raven, 1993). This is a recognised non-verbal measure of fluid intelligence (Woliver & Sacks, 1986) and thus gives a general measure of non-verbal ability. Table 1 illustrates the RCPM scores, and Chronological ages of each group.

Table 1 about here

Design and Procedure

Texture squares were created using PaintShopPro version 5 and were presented and responses recorded using Superlab version 2.0. Texture squares either consisted of a uniform texture (nonsegmented texture squares) or were composed of a uniform texture with the exception of a discrepant square patch of elements (segmented texture squares), as shown in Figure 1. Textures were composed of black elements on a white background. For the shape, proximity, luminance, size and alignment conditions the local elements of the uniform texture were open circles of 9 pixels in diameter. For the texture employed in the orientation condition, the elements were 45º oblique lines 10 pixels in length and one pixel across. For the texture employed in the closure condition the elements were created from a square 10 pixels in height and width, with a vertical slice cut through the centre removing one pixel of information from the top and bottom edges of the square. The two ‘halves’ were then vertically misaligned by 5 pixels. For all textures, except for the alignment condition, the local elements were organised into slightly misaligned rows and columns of approximately twelve elements. Elements were spaced by between 11 and 20 pixels from the edge of one element to another. For the alignment condition the open circle elements described above were aligned, spaced 11 pixels from edge to edge, in a 12 by 12 formation.

The discrepant patch in the segmented texture squares involved either 16 (4 by 4) or 9 (3 by 3) elements, as difficulty levels 1 and 2 respectively. These elements differed from the remaining elements of the uniform texture by one of seven properties: size (circles were larger: 15 pixels in diameter), luminance (circles remained 9 pixels in diameter, but were filled in black), proximity (each gap between elements featured an additional circle, also 9 pixels in diameter), shape (elements were squares of 8 pixel height and width), closure (element pairs were aligned), orientation (lines were rotated 90º from the main texture) and alignment (the elements were aligned: circles of 9 pixel diameter were spaced by a 10 pixel gap between circle edges horizontally and vertically).

For all trials, two squares of texture were simultaneously presented on a computer monitor, one to the left and one to the right of centre. For 'same' trials, two identical nonsegmented texture squares were presented. For 'different' trials, one segmented texture square and one nonsegmented texture square were presented (see Figure 2). For each condition, the same texture type was employed throughout. For example, for the orientation condition, texture squares (segmented and nonsegmented) of the line element texture only were used, and for the luminance condition all texture squares were composed of the open circle texture.

Participants were asked to press one of two key pads to indicate whether the texture squares were the same or different. The two $2cm^2$ key pads, located on the left and right of the keyboard, depicted a green tick ('same' response) and a red cross ('different' response) respectively. Stimuli remained on the screen until a correct response had been made to provide participants with feedback. This was followed by two mask texture squares presented in the same position as the experimental texture squares, for 300ms before the next trial began. The mask texture was composed of lines of random length and orientation.

The experiment started with a block of 14 practice trials. This included one same and one different trial from each of the seven different segmentation types, presented in a random order. Participants had the opportunity to repeat the practice block, but in practise this was not necessary as all participants understood the procedure. There were seven experimental blocks, one for each segmentation type. Each block involved 16 trials (all of the same segmentation type), eight 'same' and eight 'different', presented in random order. Of the eight 'different' trials, four of the trials had a discrepant patch of 16 elements (level 1) and four trials had a discrepant patch of 9 elements (level 2). For each, the discrepant patch was in the left or right texture square equally. To counteract any order effects, two fixed-random orders of blocks of segmentation type, were employed. Thus, half of the participants received one order of blocks, whilst the other half received the other order of blocks. Participants had the opportunity to have a break between blocks if required. The experiment took a maximum of 15 minutes to complete. Participants also completed the RCPM and two other tasks not presented here. Testing was over one (WS group) or two (TD controls) sessions, and did not take more than fifty minutes in total.

Figures 1 and 2 about here

Results

Number of correct responses

ANOVA of the number of correct responses, with response type (same, different), segmentation type (seven levels) and group (WS, TD) as factors was carried out. Adjusted F-values are reported (Greenhouse-Geisser correction) as sphericity cannot be assumed. The main effect of group was not significant (F<1) and there was no main effect of response type (F<1). Response type did, however, interact with segmentation type ($F(4.28, 162.52)=2.76$, $p=.01$, partial $\eta^2=.07$). This was due to more accurate ‘same’ than ‘different’ response for grouping by alignment ($t(39)=2.45$, $p=.02$), but not for the remaining grouping types (p>.05). This interaction did not differ by group, nor was there a group by response type interaction (F<1 for both). There was a main effect of segmentation type, $F(4.62, 175.73)=6.79$, $p<.001$, partial $\eta^2=.15$ (closure, proximity, size > alignment, orientation, shape; luminance > alignment, orientation, $p<.05$ for all). The interaction between group and segmentation type was not significant, $F(4.62, 175.73)=1.62$, $p=.16$, partial $\eta^2=.04$, suggesting a typical profile of texture segmentation abilities in WS. Independent sample t-tests for each segmentation type supported this (p>.05 for all). The number of correct responses to same and different trials (maximum 16) is shown in Figure 3.

‘Different’ trials had two difficulty levels. Difficulty level was analysed by a further ANOVA on the number of correct responses to ‘different’ trials only, which included a difficulty level factor (trials with 9- or 16-element discrepant patches). Results showed a main effect of difficulty level, $F(1, 38)=4.67$, $p=.04$, partial $\eta^2=.11$ (9-element patches < 16-element patches). However, this interacted with segmentation type ($F(6, 228)=3.15$, $p=.01$, partial $\eta^2=.08$), which after exploration, showed that 9-element patches were only more difficulty than 12-element factors for two segmentation types (alignment and orientation, $p<.05$ for both). Difficulty level did not interact with group, $F(1, 38)=1.17$, $p=.29$, partial $\eta^2=.03$. The remaining effects were comparable to the analysis above.

Figure 3 about here

Response times

Mean response times (RT) were calculated from correct responses only, for each segmentation type, for ‘same’ and ‘different’ trials separately. There were no missing values. ANOVA was carried out with group as a between participant factor (WS, TD) and segmentation type (7 levels) and response type (same, different) as within participant factors. Adjusted F-values are reported (Greenhouse-Geisser correction) as sphericity cannot be assumed. The main effect of group was not significant, $F<1$. There was a significant main effect of segmentation type, $F(3.70, 140.48)=7.32$, $p<.001$, partial $\eta^2=.16$. This was not dissimilar to the pattern of number of correct responses above (RT: orientation > luminance, proximity, shape, size, alignment, shape > luminance, proximity, size; closure > luminance, size; all other > size, $p<.05$ for all). The main effect of response type was significant on account of quicker ‘same’ responses than ‘different’ responses, $F(1.00, 38.00)=5.97$, $p=.02$, partial $\eta^2=.14$. There were no significant interactions, segmentation by group, $F(3.70, 149.48)=1.73$, $p=.15$, partial $\eta^2=.04$, all remaining, $F<1$. As with the correct response data, independent samples t-tests for each segmentation type supported the lack of group by segmentation type interaction (p>.05 for all).

ANOVA was carried out on ‘different’ trials to explore the factor of difficulty level (2 levels). This revealed no effect of difficulty level or interaction with group (F<1 for both) and so is not discussed further.

Discussion

It appears that the ability to segment textures in WS is commensurate with the general level of visuo-spatial ability observed in this population. Importantly, there was no indication that the profile of segmentation ability across gestalt principles differed from that of matched typically developing controls. This contrasts to what is known about perceptual grouping in WS where performance according to certain gestalt principles is impaired relative to other principles (Farran, 2005). This could relate to differences between integration and segmentation. Perhaps the ability to focus on dissociations between local elements, necessary for successful segmentation, is more robust across gestalt principles than the ability to focus on similarities between elements, a requirement of integration.

Before conclusions can be drawn, one must consider task differences between the segmentation task employed here and the integration task in Farran (2005). The integration task required the individual to make a perceptual judgement, i.e. are the elements grouped horizontally or vertically? In contrast, the texture segmentation task only asked the individual to detect the presence of texture segmentation, and to give a ‘different’ response if one of the texture squares contained segmentation, or a ‘same’ response if neither texture square contained segmentation. It is possible that any atypical patterns of segmentation performance were not expressed due to the low computational demands of the task.

Computational differences could also be a contributory factor to the pattern of results reported by Reiss et al.’s (2005) across motion coherence tasks. Their form-from-motion task, where performance was relatively poor in WS, required the individual to make a perceptual judgement relating to the orientation of a discrepant patch of texture. In contrast, the motion coherence task and biological motion task, where performance was relatively strong, was similar to our Experiment 1, i.e. participants had to detect the presence of a discrepant patch of texture.

Experiment 2

Given the computational differences between Experiment 1 and Farran (2005), and in light of Reiss et al. (2005), it is possible that patterns of performance might differ if participants were asked to make a perceptual judgment in a texture segmentation task. This is explored in Experiment 2. In this Experiment, first segmentation always occurred and second, participants were asked to make a decision regarding the segmented area. Participants indicated whether the segmented area resembled the shape of a letter E or a letter H. Segmentation was according to one of six gestalt principles. These were the same principles as those used in Experiment 1, with the exception of alignment, which was not included due to difficulty with creating coherent stimuli.

A further consideration is made in this Experiment. An atypical profile of texture segmentation abilities in WS relative to matched controls indicates deviance relative to their general level of visuo-spatial ability. However, the profile of performance of the individual with WS might be comparable to the profile of typical development at an earlier or later point along the developmental trajectory. To explore this possibility, Experiment 2 employed a developmental trajectory approach, in which WS performance was compared to the trajectory of texture segmentation ability, measured from four years to eight years of typical development.

Method

Participants

Eighteen individuals with WS took part. As in Experiment 1, all participants had been genetically diagnosed using the FISH test, and phenotypically diagnosed by a clinician. Fifty typically developing children also took part, ten individuals for each age group from 4 to 8 years. The level of visuo-spatial ability of all participants was assessed using the Ravens Coloured Progressive Matrices (RCPM; Raven, 1993). From previous experience, and the scores on the RCPM, it was estimated that the age range of the typically developing children was appropriate to cover the range of abilities on the experimental task exhibited by the WS group. Table 2 illustrates the RCPM raw scores, and chronological age of each group.

Table 2 about here

Design and Procedure

As in Experiment 1, texture squares were created using PaintShopPro version 5 and were presented and responses recorded using Superlab version 2.0. Participants were presented with one texture square in the centre of a computer monitor. The texture elements were identical to those used in Experiment 1: open circles of 9 pixel diameters, 45º oblique lines (10 pixels by 1 pixel) and misaligned halves of a square of diameter 10 pixels (closure condition only). In this Experiment, the elements were spaced by a 10 pixel gap, and were aligned horizontally and vertically in a formation of approximately 12 by 12 elements. In each texture square, a number of elements differed from the remaining elements according to one of six gestalt principles listed below. The critical elements formed the shape of an ‘E’ or an ‘H’. In the least difficult trials (level 1), the critical elements were the only elements that differed from the remaining texture. Difficulty was increased by two levels by changing a further 6 (level 2) or 12 (level 3) elements in addition to the critical elements according to the same principle, thus subtly disrupting the background texture. Six gestalt principles were employed (see Figure 4). These were similar to those employed in Experiment 1, as follows: size (circles were larger: 15 pixels in diameter), luminance (circles remained 9 pixels in diameter, but were filled in black), proximity (each gap between elements featured an additional circle, also 9 pixels in diameter), shape (elements were squares of a 8 pixel height and width), closure (element pairs were aligned to form closed squares), orientation (lines were rotated to horizontal). As mentioned, alignment was not included in this Experiment due to difficulty with creating coherent stimuli.

Figure 4 about here

Participants were asked to press one of two 2 cm^2 key pads, which depicted a capital E and a capital H as to whether they thought the discrepant patch of critical elements resembled and E or an H. In order to give feedback, the trial only moved on when a correct response had been given. Each texture square was followed by a mask texture square, presented at the same location as the experimental texture square, for 300 msecs before the next trial began. As in Experiment 1, the mask texture was composed of lines of random length and orientation. The experiment began with a practice block of 12 trials, two from each segmentation type, in a random order. Participants had the opportunity to repeat this block until they understood the task. All participants only needed to complete the block once. There were 72 experimental trials. These were presented in blocks according to segmentation type. Each block consisted of 12 trials, two E and two H trials, for each of the three levels of difficulty. Within each block, the letter (E or H) appeared in one of four locations within the texture square. Trials were randomised within each block. To counteract any order effects, there were two orders of presentation of the six experimental blocks. Half of the participants received one order of blocks and the other half received the other order of blocks. All participants took part in this experiment as part of a battery of four tasks, the order of which was counterbalanced. The total testing time was one hour, with the current task taking approximately 15 minutes. Testing was completed in one (WS) or two (TD groups) sessions. Participants were given breaks both between blocks within the task and between tasks where needed.

Results

Number of correct responses

Due to ceiling effects, the 8-year-old TD children were eliminated from this analysis (one-sample t-test: $p>.05$). Although performance of the WS group as a whole was not at ceiling ($p<.05$), two individuals scored the ceiling score for all tasks and so were removed from this analysis. Thus, the remaining TD group consisted of 40 children (N = 10 for 4-, 5-, 6, and 7-year-olds) and the WS group consisted of 16 individuals. Difficulty level was excluded as a factor as initial analysis indicated that it did not have a significant effect on performance. ANCOVA was carried out with a between participant factor of group (WS, TD), and a within participant factor of segmentation type (6 levels). Score on the RCPM was employed as a covariate in order to determine whether texture segmentation ability in WS differed from typical development beyond that expected for their level of visuo-spatial cognition. An additional interaction term was built into the model to explore any group differences in the relationship between texture segmentation ability and RCPM score. Where sphericity cannot be assumed, adjusted *F*-values are reported (Greenhouse-Geisser correction).

Results showed a significant relationship between performance and RCPM score, $F(1, 52)=9.62$, $p=.003$, partial $\eta^2=.16$, which did not interact with group, $F(1, 52)=1.94$, $p=.17$, partial $\eta^2= .04$. The main effect of group was not significant, $F(1, 52)=2.50$, $p=.12$, partial $\eta^2=.05$. However, there was a significant main effect of segmentation type, $F(3.58, 186.22)=7.31$, $p<.001$, partial $\eta^2=.12$ (closure < all other; orientation < size, proximity, shape and luminance; shape < proximity, size and luminance; size < proximity, p<.05 for all). Interestingly, as in Experiment 1, this did not interact with group, $F(3.58, 186.22)=1.15$, $p=.34$, partial $\eta^2=.02$. Despite this, univariate analysis of each grouping type showed superior WS performance compared to controls for segmentation by proximity ($F(1, 52)=9.21$, $p=.004$, partial $\eta^2=.15$, WS>TD) and a similar marginal group effect for segmentation by size ($F(1, 52)=3.40$, $p=.07$, partial $\eta^2=.06$, WS>TD). One could cautiously suggest that this reflects an atypical profile of segmentation ability in WS. Segmentation type interacted significantly with the variance associated with RCPM score, $F(3.58, 186.22)=2.71$, $p=.02$, partial $\eta^2= .05$. This was because RCPM score was associated with segmentation by closure and shape only (p<.05 for both). Although this interaction was not statistically affected by group (segmentation type by group by RCPM score, $F(3.58, 186.22)=1.35$, $p=.24$, partial $\eta^2=.02$), where RCPM score was not associated with performance, this was predominantly driven by the WS group: orientation (overall, $p=.06$; WS: $p=.95$; TD: $p<.001$), size (overall, $p=.06$: WS: $p=.67$; TD: $p=.01$), proximity (overall, $p=.10$; WS: $p=.19$; TD: $p=.001$), luminance (overall, $p=.24$; WS: $p=.68$ TD: $p=.12$). Figure 5 shows mean scores for each segmentation type, whilst Figure 6 displays individual data for WS participants compared to the developmental trajectories of the TD controls.

Figures 5 and 6 about here

Response times

Mean response times (RT) to correct responses for each segmentation type were analysed by ANCOVA in the same way as the correct response data. As above, difficulty was not included as a factor as it did not have a significant effect on results. As RT is arguably more sensitive to level of performance where ceiling effects are concerned, the 8 year-old-children and the two WS individuals with ceiling scores were included in this analysis.

Greenhouse-Geisser corrected F-values are reported (sphericity not assumed). Results showed that RTs were significantly related to RCPM score, $F(1, 64)=15.54$, $p<.001$, partial $\eta^2=.20$. This marginally interacted with group, $F(1, 64)=3.31$, $p=.07$, partial $\eta^2=.05$. This was because RTs were related to RCPM scores for the TD group only (TD: $F(1, 48)=39.29$, $p<.001$, partial $\eta^2=.45$; WS: $F<1$). The main effect of group showed marginal significance due to longer RTs in the WS than the TD group, $F(1, 64)=2.94$, $p=.09$, partial $\eta^2=.04$. The main effect of segmentation type was significant, $F(3.41, 218.16)=3.53$, $p=.01$, partial $\eta^2=.05$. This pattern was broadly consistent with the correct response data (RT: proximity <size, shape, luminance and closure; orientation < shape). This did not interact with group, $F(3.41, 218.16)=1.97$, $p=.11$, partial $\eta^2=.03$. However, univariate analysis indicated that for segmentation by orientation, the WS group in fact showed quicker responses than controls ($F(1, 64)=7.46$, $p=.01$, partial $\eta^2=.10$), and marginally slower responses for luminance ($F(1, 64)=3.31$, $p=.07$, partial $\eta^2=.05$). All remaining interactions were not significant: segmentation type by RCPM score, $F(3.41, 218.16)=1.61$, $p=.18$, partial $\eta^2=.03$; segmentation type by group by RCPM, $F(3.41, 218.16)=1.78$, $p=.15$, partial $\eta^2=.03$.

Mental age calculations

The mental age equivalent for the level of ability of each individual with WS was calculated by matching WS correct response performance to the typically developing trajectory of correct response performance. Correct responses were chosen over RTs for this analysis, as they are a more reliable measure of performance and less affected by the attention and distractibility of the participant. ANCOVA was carried out for the scores of the TD controls only (4- to 7-year-olds, N=40) with CA as a covariate. This was to determine first whether performance was associated with CA and second whether there was an effect of difficulty level. Results showed that CA was associated with performance in the TD controls, $F(1, 38)=27.43$, $p<.001$, partial $\eta^2=.42$ and that there was no effect of level of difficulty, $F(2,$

76)=1.72, p=.19, partial η^2=.04. In light of these results, the developmental trajectory of TD performance was determined for each grouping type using linear regression. Difficulty level was not included as a variable and so scores were out of a maximum of 12. Performance on all segmentation types was significantly linear (p<.05 for all). The linear equations for each trajectory were employed to predict the mental age for each individual with WS based on their score out of 12 for each segmentation type. The linear function was not extrapolated below the dataset. Although this has the effect of reducing the range of mental age calculations, we did not want to make assumptions beyond the age range measured. Thus, where a WS score was equivalent to a mental age below 4-years, this was replaced by a mental age of 4-years. Similarly, on occasions when an individual with WS scored the ceiling score of 12, note that a higher level of performance might have been masked, and thus the mental age calculated might have been artificially low for that individual. Note that in typical development, by 8 years ceiling performance is reached on these tasks. The mean mental age for each individual with WS was calculated across all six segmentation types. As expected, this was not correlated with CA, Pearson correlation coefficient = 0.33, p=.18. Overall, the mental age of individuals with WS on this task was 6;2 (years; months), range 5;0 to 7;2. Mental age is plotted against CA in Figure 7. The two individuals with WS who were performing at ceiling can be clearly seen from the standard error bars and so the calculations of their mental age, mean 7;2 years, might not be representative of their level of texture segmentation ability. However, we are confident that the mental age calculations of the remaining individuals are representative of their level of ability on this task.

Figure 7 about here

Discussion

Experiment 2 demonstrated that in both the number of correct responses and response time analyses, the WS group showed a pattern of performance which was generally comparable to that observed in typical development, i.e. the effect of segmentation type did not interact with group. However, due to the numerous types of segmentation employed, group comparisons were made for each segmentation type. This did show some group differences, which were not apparent in Experiment 1. We suggest that this difference in results reflects the relative computational simplicity of Experiment 1 compared to Experiment 2.

In Experiment 2, individuals with WS were more accurate at segmenting by proximity and made faster responses when segmenting by orientation than predicted by their general level of visuo-spatial cognition. This suggests some atypicality in the profile of segmentation abilities in WS. Indeed, Figure 6a demonstrates that a number of WS participants produced ceiling performance on the proximity condition, which indicates that this group difference could be stronger than observed here. However, as there was no RT advantage for segmenting by proximity, this is unlikely. The RT advantage observed for segmenting by orientation does not appear to reflect a strength as the effect was not accompanied by increased accuracy. This is illustrated in Figure 6d which shows that five individuals with WS achieved a score which was close to the chance score of 6. It is possible therefore, that this effect reflects a speed-accuracy trade-off in some individuals.

The relative strength in WS for segmenting by proximity is not consistent with integration performance: Farran (2005) reported proximity as a relative weakness within the profile of perceptual grouping abilities in WS. In the current Experiment, the proximity stimuli were the only stimuli in which the local elements did not change their identity, and in which the spatial layout was altered. Although this difference holds for both integration and segmentation tasks, it appears that it is only an advantage to individuals with WS when segmentation is required. At this point, it is important to consider the precise demands of segmentation tasks such as that employed here. Clearly segmentation ability is required to detect the presence of dissociations within the texture. However, to identify the elements as forming a letter shape appears to require the ability to integrate. As such, we suggest that this task, although mostly weighted towards segmentation ability, does in fact also require the ability to integrate. One could tentatively suggest that if the balance of segmentation and integration requirements for the proximity stimuli differs from that of the other stimuli, this might explain the anomalous level of performance on this task in WS. However, as it is likely that integration is more heavily weighted in this task, this explanation is not consistent with the relative weakness in integrating by proximity observed in WS (Farran, 2005) and so cannot be supported without further investigation. As such, the relative strength in segmenting by proximity in WS is difficult to interpret.

In Experiment 1, level of performance did not differ from typically developing children of mean age 5;11 years. This is commensurate with their general level of visuo-spatial cognition (as measured by the RCPM). Experiment 2 took a developmental trajectory approach. This better enabled us to take any variability in level of visuo-spatial ability into account. Overall, the level of performance of individuals with WS did not differ from that expected by their general level of visuo-spatial cognition, although they did show a trend for slower responses than controls. This is approximately similar to the level of performance observed in Experiment 1. Mental age measures, based on the typical developmental trajectory indicated that the WS group as a whole performed at the level of a typically developing individual of 6;2 years, again comparable to level of performance in Experiment 1, although note that mental age ranged from 5;0 to 7;3, which is quite substantial group variability. This is not unusual for this population (see Thomas et al., 2001; Karmiloff-Smith et al., 2004).

General Discussion

Experiments 1 and 2 demonstrated that on average segmentation ability is poor in WS, with individuals functioning at the level of a typically developing 6-year-old. This is commensurate with their general level of visuo-spatial cognition. Similarly, Reiss et al. (2005) and Atkinson et al. (2003) also report segmentation ability in WS which is comparable to typically developing 6-year-olds and 5-year-olds respectively. Importantly, the pattern of segmentation abilities is typical in this group when segmentation is determined by the identity of local elements, but is relatively strong when segmentation is determined by proximity. Note that Atkinson et al. (2003, 2006) reported a discrepancy between segmentation by good continuation and by motion in WS, although only in a subset of children with WS (Atkinson et al., 2003). They fitted this discrepancy to the portion of the developmental trajectory observed in a typically developing 4-year-olds, which demonstrates that the pattern of performance was a typical pattern when developmental trajectories are considered. With the exception of segmentation by proximity, the current Experiments and previous research therefore suggest that the ability to segment a global figure into its component parts is accomplished in a typical manner in WS.

Previous investigation, using Navon figures (Navon, 1977) demonstrated that the balance of local and global perceptual processing in WS was comparable to controls (Farran et al., 2003). Despite this, one cannot assume that the perception of local and global elements is reached in a typical manner in WS. Indeed, further investigation revealed that the integration of local elements into a global form might not be accomplished in a typical manner in WS (Farran, 2005). The present study showed that, in contrast, the ability to segment a global form into local units is broadly typical in WS. Thus, despite a typical balance of local and global perceptual processing in WS, this reflects both typical and atypical underlying processes.

Cortical activation of areas V1 and V2 is associated with both integration (Kapadia, Westheimer, & Gilbert, 1998) and segmentation (Grosof et al., 1993), whilst activation of V4 and TEO is reported for segmentation (Kastner et al., 2000) but not for integration. One could argue that the discrepancy between integration and segmentation performance in WS suggest that areas V1 and V2 show some atypical function, but that V4 and TEO are less impaired (with respect to segmentation ability). Neuroanatomical investigation describes abnormalities in V1 in WS (Galaburda & Bellugi, 2000; Galaburda et al., 2002), which supports the notion that functioning in V1 is atypical in WS. Areas V2, V4 and TEO have not been specifically investigated in WS. One cannot make assumption about neuroanatomical function based on behavioural evidence only. Perhaps future investigations of specific cortical areas of the WS brain will shed light on our behavioural findings.

In summary, the present results demonstrate that some aspects of perceptual processing in WS show a typical pattern, despite low levels of ability. This shows empirical support to the previous assumption that the ability to segment an object into its local parts is broadly typical in WS.

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Table 1: Experiment 1, participant details: Chronological Age (CA) and non-verbal ability (Ravens Coloured Progressive Matrices: RCPM) score for each group

Group	CA: Mean (S.D.)	RCPM score: Mean (S.D.)
Williams syndrome (N=20)	21;2(10;6)	16.80(6.57)
Typically developing (N=20)	5;11 (0;5)	16.85 (6.29)

Table 2: Experiment 2, participant details: Chronological Age (CA) and non-verbal ability (Ravens Coloured Progressive Matrices: RCPM) score for each group

Group	CA (years; months): mean(SD)	RCPM score: mean(SD)
Williams syndrome (N=18)	20;10 (0;10)	17.61 (6.52)
Typically developing (N=50)		
4-year-olds	4;2 (0;1)	12.78(4.27)
5-year-olds	5;1(0;2)	15.11 (3.10)
6-year-olds	6;1(0;3)	16.78(4.76)
7-year-olds	6;10(0;3)	23.70(3.16)
8-year-olds	8;1(0;2)	24.60(3.84)

Figure captions

Figure 1: Experiment 1 stimulus set (seven gestalt principles, 2 difficulty levels)

Figure 2: Experiment 1, example ‘same’ and ‘different’ trial types

Figure 3: Experiment 1 correct responses by segmentation type: Mean (S.E.)

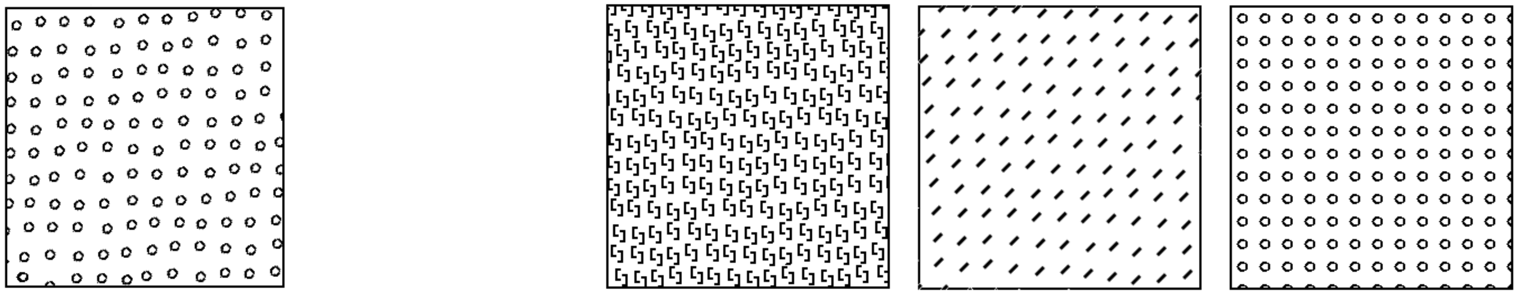
Figure 4: Experiment 2 stimulus set (six gestalt principles, 3 difficulty levels)

Figure 5: Experiment 2 correct responses by segmentation type: Mean (S.E.)

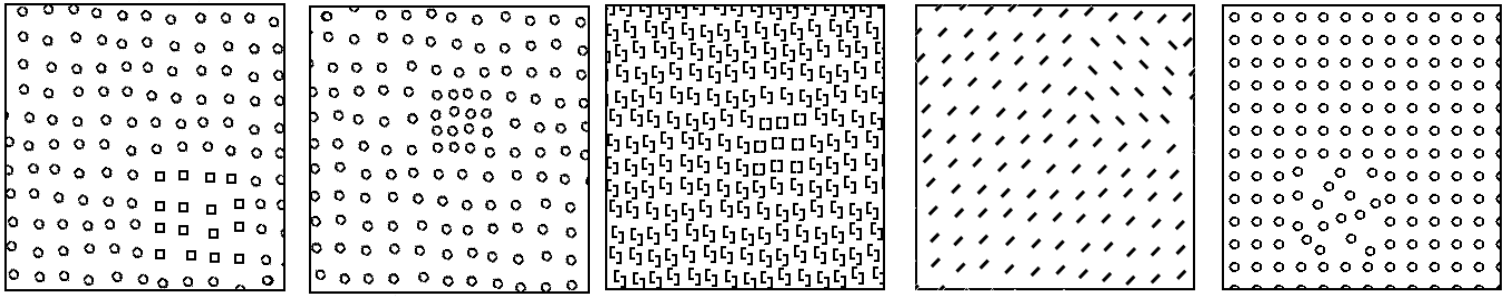
Figure 6: Experiment 2, individual correct response scores for participants with WS and developmental trajectories for TD participants, plotted against Ravens Coloured Progressive Matrices (RCPM) score.

Figure 7: Experiment 2 WS Mental Age scores (Mean and S.E.) on segmentation task plotted against Chronological Age (CA)

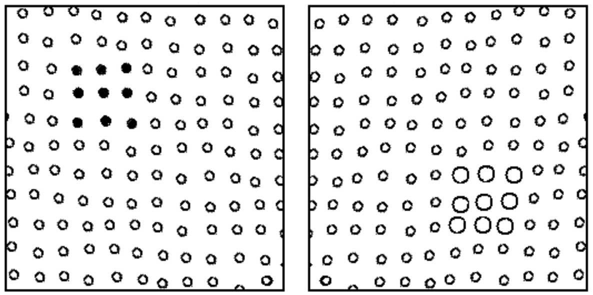
Non-segmented textures



Segmented textures (level 1: 16-element discrepant patch; level 2: 9 element discrepant patch)

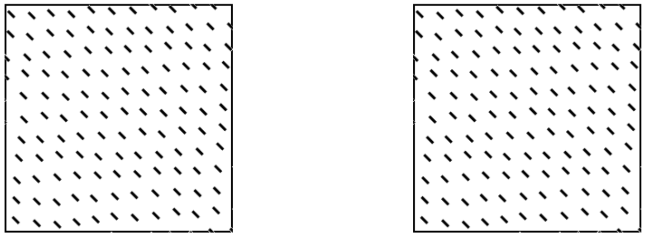


Shape, level 1   Proximity, level 1   Closure, level 2   Orientation, level 1   Alignment, level 2

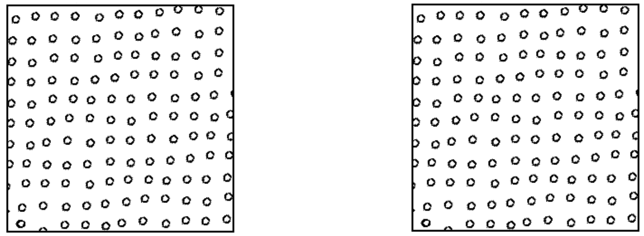


Luminance, level 2   Size, level 2

Example ‘same’ trials

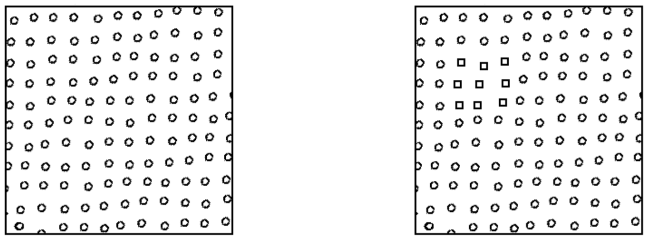


Same trial: Employed for orientation segmentation block

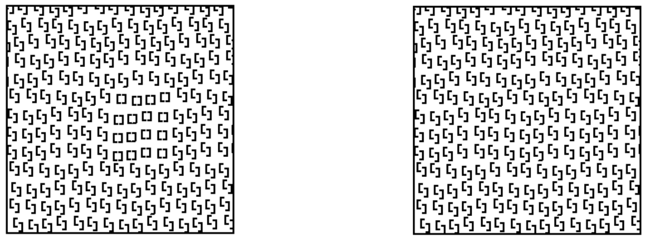


Same trial: Employed for luminance, size, shape & proximity blocks

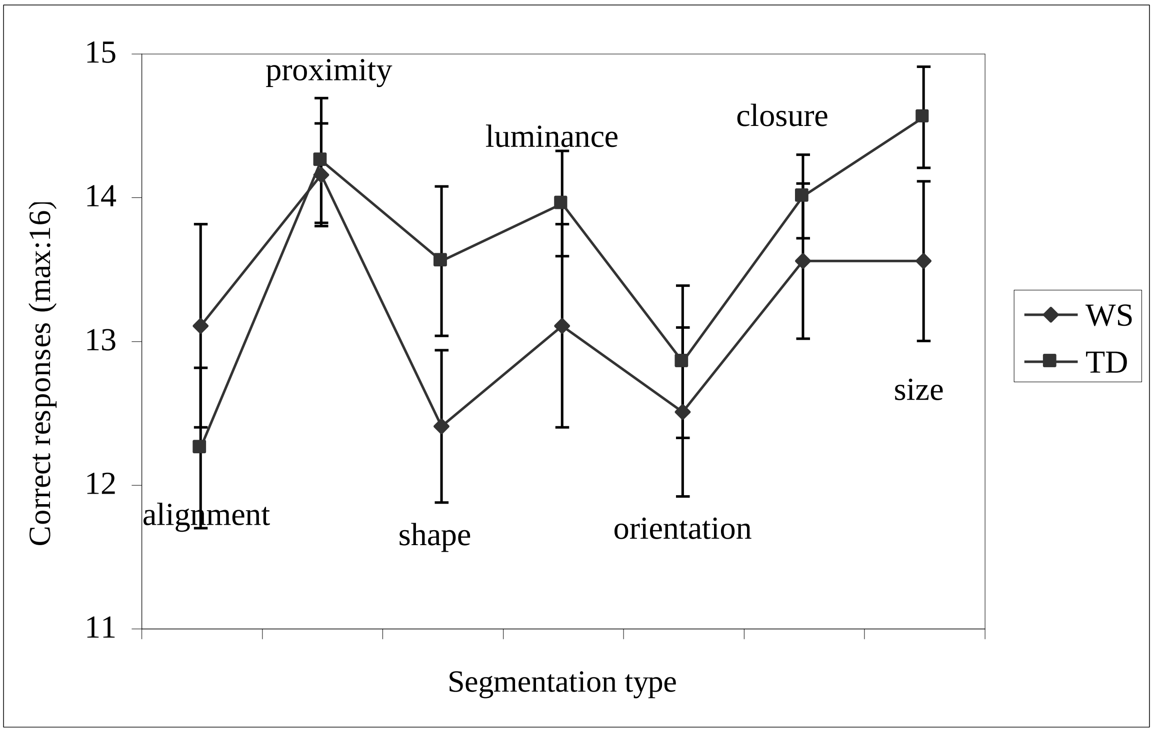
Example ‘different’ trials

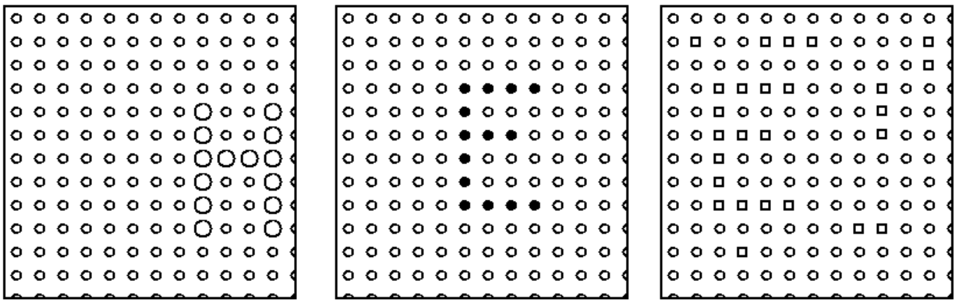


Different trial: Segmentation by shape, level 2

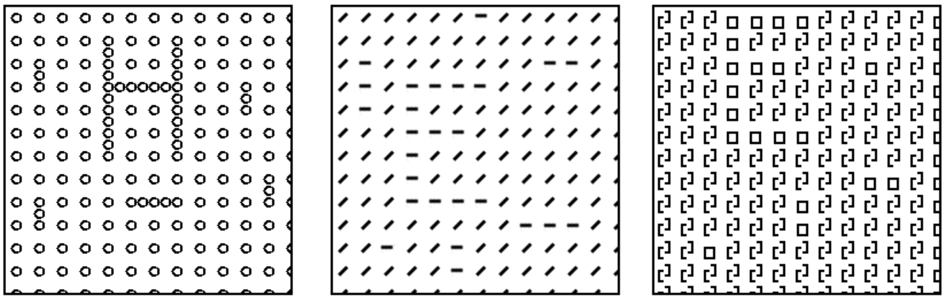


Different trial: Segmentation by closure, level 1


15
14
13
12
11
Correct responses (max:16)
proximity
luminance
closure
alignment
shape
orientation
size
WS
TD
Segmentation type



Size, level 1 Luminance, level 1 Shape, level 3

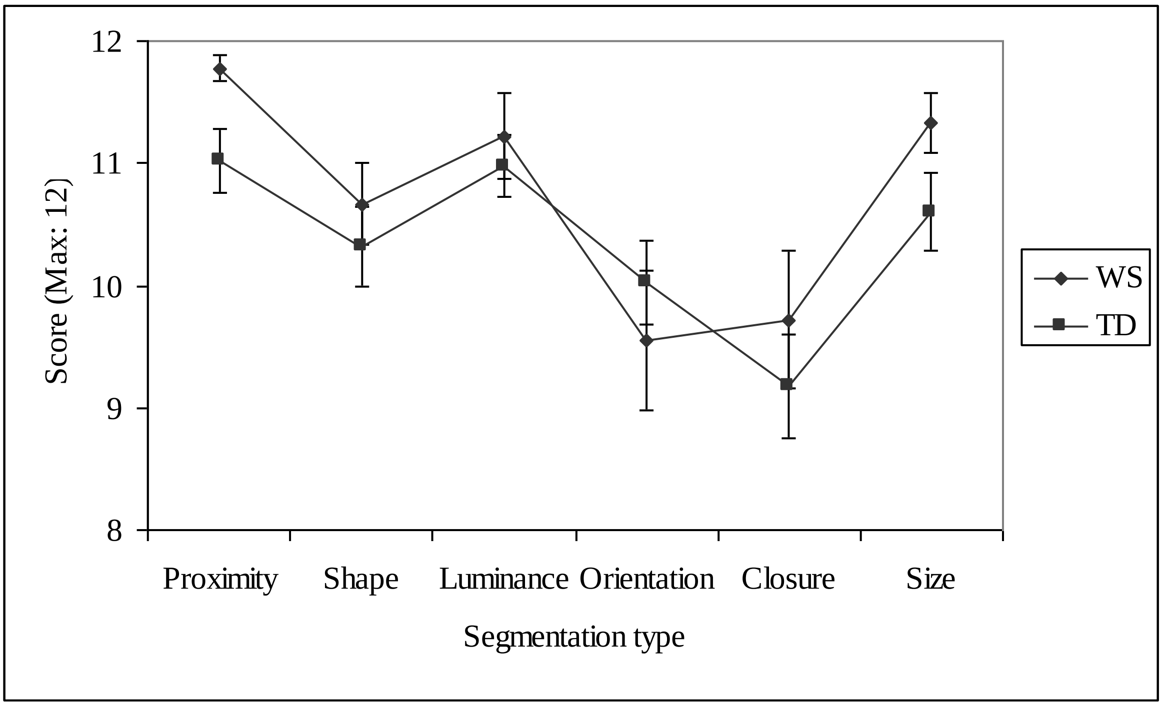


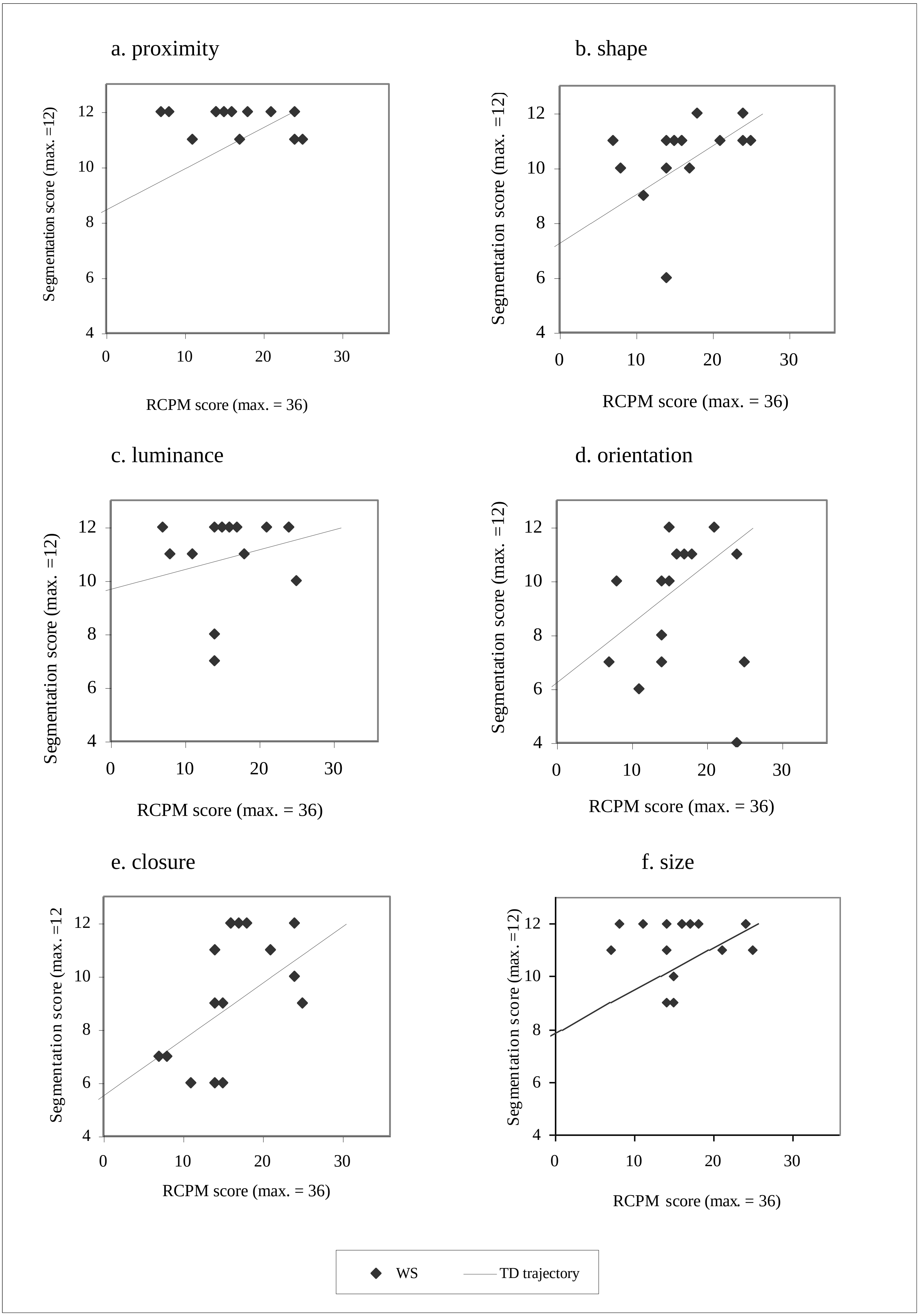
Proximity, level 2 Orientation, level 3 Closure, level 2

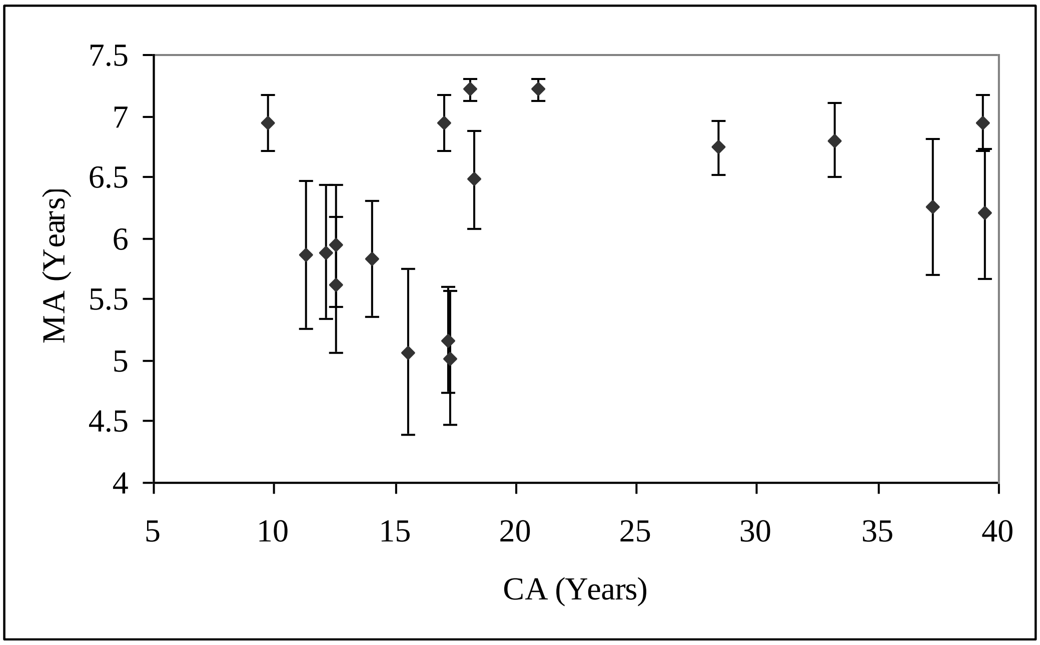
level 1: 0 distracter elements

level 2: 6 distracter elements

level 3: 12 distracter elements


12
11
10
9
8
Score (Max: 12)
Proximity
Shape
Luminance
Orientation
Closure
Size
Segmentation type
WS
TD


a. proximity
b. shape
c. luminance
d. orientation
e. closure
f. size
Segmentation score (max. =12)
RCPM score (max. = 36)
12
10
8
6
4
0
10
20
30
WS
TD trajectory


7.5
7
6.5
6
5.5
5
4.5
4
MA (Years)
5
10
15
20
25
30
35
40
CA (Years)