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A «Visual Conflict» Hypothesis for Global-Local Visual Deficits in Williams Syndrome: Simulations and Data

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Abstract

Individuals with Williams Syndrome demonstrate impairments in visuospatial cognition. This has been ascribed to a local processing bias. More specifically, it has been proposed that the deficit arises from a problem in disengaging attention from local features. We present preliminary data from an integrated empirical and computational exploration of this phenomenon. Using a connectionist model, we first clarify and formalize the proposal that visuospatial deficits arise from an inability to locally disengage. We then introduce two empirical studies using Navon-style stimuli. The first explored sensitivity to local vs. global features in a perception task, evaluating the effect of a manipulation that raised the salience of global organization. Thirteen children with WS exhibited the same sensitivity to this manipulation as CA-matched controls, suggesting no local bias in perception. The second study focused on image reproduction and demonstrated that in contrast to controls, the children with WS were distracted in their drawings by having the target in front of them rather than drawing from memory. We discuss the results in terms of an inability to disengage during the planning stage of reproduction due to over-focusing on local elements of the current visual stimulus.

Introduction

Williams Syndrome (WS) is a rare genetic disorder characterized in part by disorders in visual perception (Atkinson et al., 2001). One particular WS visual deficit involves preferential perception of the component parts of global forms, rather than the global forms themselves. A possible explanation of this global-local perceptual deficit is the local-bias hypothesis (e.g., Bihrlé et al., 1989), whereby individuals with WS tend to focus on local details and fail to adequately process global visual forms. Fayasse and Thibaut (2002) found that a greater number of local components actually impairs WS individuals' performance compared to TD children. They further hypothesized that this difficulty might stem from an inability to disengage attention from local features. Brown et al. (2003) found deficits in the saccade planning of toddlers with WS and similarly interpreted these in terms of an attention disengagement

deficit. However, it remains unclear the extent to which the primary impact of the deficit lies in perception or construction (e.g., Pani et al., 1999; Rossen et al., 1996). Farran, Jarrold, and Gathercole (2003) have recently argued that individuals with WS only have a local bias in their drawing and not in their identification. Atkinson et al. (2003) have suggested that construction impairments stem from frontal control processes that are associated with spatially directed responses.

Vicari et al. (2003) demonstrated that in children with WS, form information is maintained relatively intact in Short Term Memory (STM) whereas location information is not processed correctly. Since reproduction is a more complex task that depends on, at the very least, integrating both form and location information, it is possible that children with WS may be able to retain a global image in visual working memory, leading to relatively good performance on image-recognition tasks, but express a local bias when it comes to planning the drawing of individual elements in a copying task.

In exploring the underlying causes of the visuospatial deficit in WS, a central difficulty is the vague specification of the local bias hypothesis. What is a sensible formalization of an image recognition or reproduction task; how might one encode sensitivity to local versus global levels of organization in a sequential task, either of saccading the elements of a display or reproducing elements of that display in a particular organization; what parameter would be sufficient to mediate attention to global or local organization, that might operate in the typically developing system but explain anomalous behavior in the atypical system? Our first step in this paper is to turn to computational modeling to formalize the hypothesis of an inability to locally disengage, and establish that an account of this nature is sufficient to demonstrate the behavior observed in WS visuospatial construction skills.

The SRN simulation

For consistency with previous empirical work in this area, we focused on recognition and reproduction of Navon-type

geometrical stimuli (Navon, 1977). These are figures in which a large letter (e.g., the letter H) is made up of smaller letter's (such as Ss), so that the overall figure has both a global (H) and local (S) level of organization.

In order to capture the task of simultaneously representing these two levels of organization, we used a simple recurrent network (SRN) encoding “what” and “where” information on object location (Elman, 1990; Rueckl, Cave & Kosslyn, 1989). The model was presented with a complex figure and sequentially encoded both the position and identity of each local element. The model was free to alter which position it was processing and by scanning the Navon figure, the model could therefore encode global organization in the form of a sequence. Figure 1 depicts a canonical scan order for processing an H made of Ss, although the model was free to saccade anywhere on the global figure at any time. To correctly reproduce the global H, the model had to learn: (i) a sequence of *locations* that make up the global H and, at the same time, (ii) the shape of the component S's associated with each location comprising the H.

Most importantly, the model included a local-attention parameter. When processing a particular location, there was a certain probability that for the next weight-change cycle it would remain at that location, as opposed to moving to the next sequential location or saccading to another part of the global figure. The aim of the simulation was modest. Using the Navon figure in Figure 1, we explored how the ability of the model to encode this stimulus would be disrupted by the local attention parameter, when this parameter assumed a single setting throughout training – could one setting of the parameter produce image-reproduction behavior observed in typically developing children whilst another setting, corresponding to a reduced propensity to disengage, would generate the WS pattern? Our evaluation of the model's performance was qualitative, assessed against the drawings collected by Fayasse and Thibaut (2002) (Fig. 2).

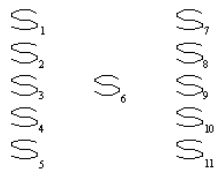


Figure 1. The prototypical Navon H, with the canonical scanning order indicated

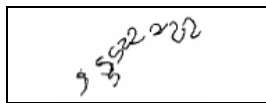


Figure 2. : Direct copying of the Navon H by a WS child (Fayasse & Thibaut, 2002).

Simulation details

Architecture. The what-where simple recurrent network model is shown in Figure 3. The local S's were coded over 72 bits (i.e., 12 locations on a 7x5 grid. The x and y locations of the S's on the global H were binary-coded with

6 bits (3 bits per coordinate). The network can be viewed as a standard SRN designed to learn the sequence of S-positions on the H, and at the same time associate each position with the letter found there (in this case, an S). Training phase. There were 56 inputs and a bias node, 50 hidden units, and 78 outputs. The learning rate was 0.01, with a momentum of 0.9, and a convergence criterion of 0.2. The model was exposed to the target for 1000 learning cycles. The local-attention parameter represented the probability that the network would continue to process the same location on the next update cycle, as opposed to shifting to another part of the global figure, either its canonical successor (see Fig. 1) or to another randomly chosen location on the H. To simulate the performance of typically developing children, the local-attention parameter was set to $p=0.2$. In line with the local bias hypothesis, to simulate an atypical system, this probability was set to $p=0.8$, implementing a relative failure to disengage from local elements. Reproduction phase. During testing of the trained network, an initial location was input to the model and it was then left to produce the sequence it had learned while studying the Navon H.

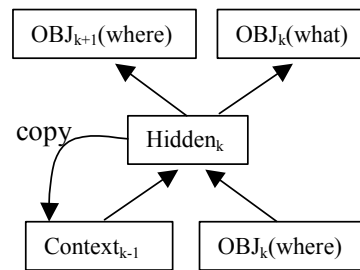


Figure 3. A simple “what-where” recurrent network model for scanning the Navon H

Results

We begin with the simulation of typical development. When the local-attention parameter value was low, the model qualitatively replicated the correctly drawn Navon figure.. Both local and global levels of organization were well formed. A representative output of the model is shown in Figure 4 (far left panel).

By contrast, a higher setting of the local-attention parameter disrupted the model's ability to learn the overall sequence of locations that would allow it to reproduce the global pattern, shown in Figure 4 (center and far right panel). On the whole, the local elements are well formed, while the global organization is impoverished. However, individual elements also exhibit anomalies since the system has had a reduced opportunity to encode the elements in certain positions and must rely on generalization from other positions.

Discussion

One specific proposal of the local bias hypothesis for visuospatial processing in WS is that these individuals have

a difficulty disengaging from local elements. Under a reasonable implementation of this proposal, we have demonstrated that a single parameter varying the probability of shifting attentional locations – was sufficient to modulate between typical and atypical patterns of behavior.

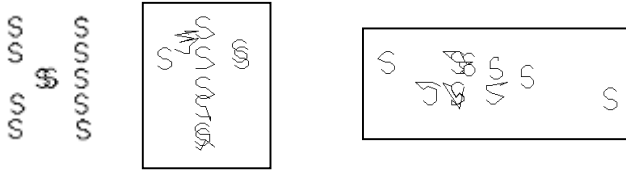


Figure 4. SRN performance on the Navon-H encoding task with a low local-attention value ($p=0.2$) (far left) simulating the performance of a typically developing system and (center and right) with a high local-attention value ($p=0.8$) corresponding to the developmentally disordered system

With a high value of the local-attention parameter, the SRN failed to correctly encode either level of organization. This demonstration of the viability of the inability-to-locally-disengage hypothesis remains in need of an explanation of why this particular parameter should be atypical in WS. This is a point to which we shall return.

First, we focus on predictions of the model. Specifically, if failure to encode the global level of organization stems from an inability to scan the full set of local elements, cues to the global organization should facilitate this process. We therefore introduce two studies in which cues to global organization were manipulated, one examining recognition, the second reproduction. In the recognition study, animation was used to increase the salience of global form. In the reproduction study, copying was done either in the presence or absence of the target. Given Vicari’s suggestion that global form is retained in visual STM, removal of the target may increase the salience of this level of organization. In both cases, should the core problem revolve around a failure to encode the global level because of attentional difficulties (rather than some more structural problem forming the representations per se), we should expect an increase in global level performance.

Study 1: Manipulating global salience in a recognition task: Static vs. Moving stimuli

In this study, participants were shown geometric Navon-type stimuli (e.g., squares, triangles and circles made up of the squares, triangles, circles, with the constraint that no figure is composed of smaller copies of itself). For each stimulus, participants were given a forced-choice selection of responding to the local elements or the global organization. To manipulate the salience of the global level of organization, various types of animation were used.

The five classes of stimuli (Fig. 5) were, in order: (i) where there was no movement of the component local elements; (ii) where a small colored contiguous group of local elements moved around the global figure; (iii) where

the elements of the global figure rotate in unison around the circumference of the global figure, (iv) where the entire global figure itself moved, and finally, (v) where each of the component elements of a global figure was jiggled randomly.

Participants

Our studies involved a group of children with WS (13 children, mean age: 8.8, SD: 2.24, range: 5.7-12.1 year) and a chronological-age matched group of typically developing (TD) children (22 children, mean age: 7.8, SD: 2.74, range: 4.0-12.5 years). Non-verbal ability was assessed using the Raven Colored Progressive Matrices (CPM) (Raven et al., 1998), for which the group mean scores were 16 and 24 for WS and control groups, respectively. The children with WS were recruited through the Williams Syndrome Foundation UK and all had tested positive for elastin deletion.

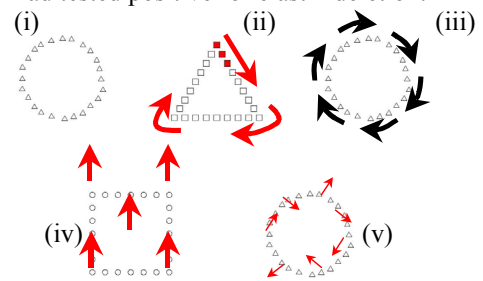


Figure 5. Various means of disengaging attention from individual local elements using movement

Experimental Procedure

Both groups of children were tested with the static and moving versions of the geometric Navon-type stimuli. The images were shown to the children for 900ms and then disappeared from the screen. The children were then asked (forced-choice detection) to chose, using a four-key answer pad, the image that best matched what they had just seen.

For example, if the target image were a global triangle made of small circles, they would have to choose from a large triangle, a small triangle, a large circle and a small circle, not necessarily in this order (Figure 7). The choice of either triangle, large or small, would constitute a “global” answer, while the selection of either circle would be a “local” answer.

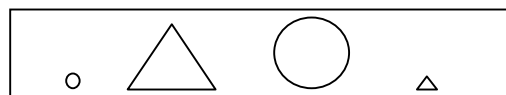


Figure 6. After seeing a global triangle made from circles, the participants must chose from the four objects above

Results

For reasons of space, we report on only the results of two of the above conditions – namely, the baseline condition in which there is no movement of the component local elements and the second condition in which a colored

segment moved around the circumference of the global figure (Fig. 5(i) and (ii)).

Figure 7 depicts the response preference for the geometric Navon stimuli. These results are notable for two things. First, the use of motion cues to increase global salience did not have an effect on preferences ($p > .5$). Second, the WS group was not significantly different from the CA-matched control group ($F(1,33) = .11, p = .74$). Given the visuospatial deficits typically reported for the disorder, this is a rather surprising finding and indicates no evidence of a recognition deficit for these stimuli.

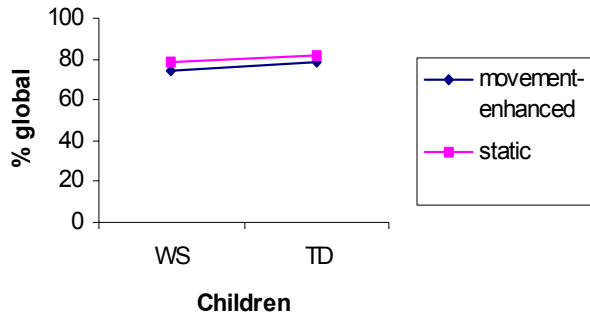


Figure 7. Comparison of TD and children with WS in recognizing the global form of movement-enhanced and static stimuli

Figure 8 (below) shows the reaction times for this global figure-recognition task for the two groups. Given the learning disability usually found in WS and evidenced by their lower scores on the CPM, it was not surprising to find slower RTs in the WS group compared to the TD group ($F(1,28) = 6.55, p = .016, \eta^2 = .23$). However, for the response times, our manipulation of global salience revealed a clear effect ($F(1,28) = 4.67, p = .039, \eta^2 = .17$) and importantly, the manipulation was equally effective in speeding the responses of both groups (interaction of stimulus type x group: $F(1,28) = 2.47; p = .130$).

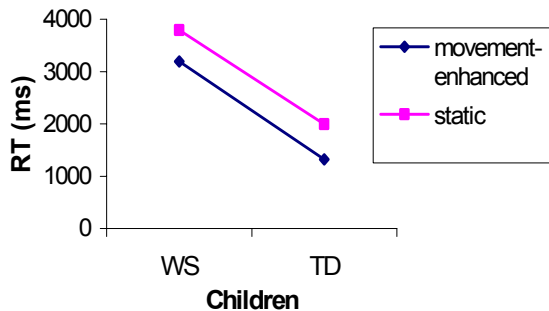


Figure 8. A comparison of global-answer RTs for TD and WS with movement-enhanced stimuli versus static stimuli

Discussion

Although children with WS were significantly slower at recognizing the global form of the target, they showed no significant difference in preference for the global form

compared to TD children. These results are intriguing in light of seemingly contradictory findings of global-local perception difficulties in individuals with WS (Bihrlé et al., 1994; Fayasse & Thibaut, 2002). However, these studies differ in two crucial respects: they involved reproducing the target rather than recognition, and they used a target that was present at all times during copying. In our second study, we switched therefore to reproduction, and explored whether the presence of the target produced differential effects in the performance of the children with WS and the TD group.

Study 2: Manipulating global salience in a reproduction task: Deferred vs. Direct copying

In this study, participants were required to copy a geometrical Navon-type figure. There were two conditions, one in which the figure remained present during copying (direct-copying condition) and the other in which the target figure was shown and masked, requiring the child to copy the figure from memory (deferred-copying condition). Importantly, in the direct-copying condition, the target is available to guide the planning stages in the recreation of the figure.

Participants

The participants were the same as in the previous study.

Experimental Procedure

Individual static Navon-type geometric stimuli, as described above, were drawn by the experimenter for the child, who was then asked to reproduce the image. In one condition, the image was shown until the child wished to begin the task and was then masked. The child was then asked to reproduce it from memory (without delay). In the other condition, the target remained visible for the child to refer to during copying.

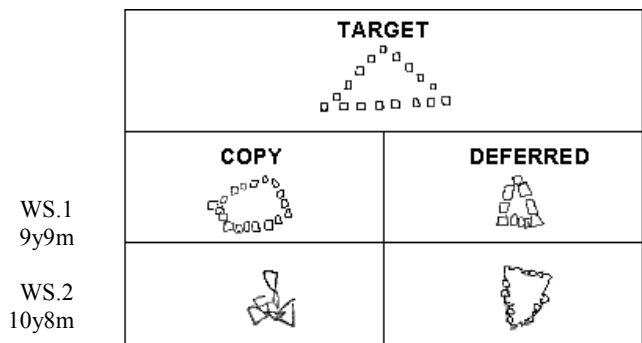


Figure 9. Representative examples of drawings by two children with WS: direct-copying versus deferred-copying

The criteria used in rating the drawings were the number of local elements drawn, the shape of the local elements, respect for configural relations between the individual components to produce a recognizable global shape, and the

quality of the overall global form. A 1-to-5 rating scale based on these criteria was used to score the drawings.

Results

The WS and TD groups demonstrated both qualitative and quantitative differences in their copying performance in the direct-copying versus deferred-copying task. Figure 9 depicts a comparison of two representative drawings, while Figure 10 plots the quantitative ratings scores. The most striking observation is that children in the WS group performed *better* when drawing from memory alone, without the physical presence of the target image to refer to during copying. For the ratings scores in Fig. 10, both main effects and the interaction were significant: for the Copying delay (direct-copying vs. deferred-copying): $F(1,32) = 22.50, p < 0.001, \eta^2 = .70$; for participant group (WS vs. TD): $F(1,32) = 19.70, p < 0.001, \eta^2 = .62$; interaction of task x group: $F(1,32) = 11.30, p = 0.020, \eta^2 = .26$. An analysis of the simple effect within the TD group revealed no significant performance difference between the direct-copying and the deferred-copying task. Some of the children did not complete the drawing test.

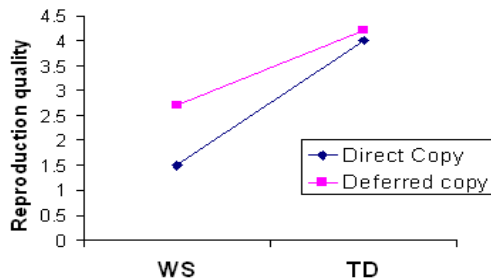


Figure 10. Drawing reproduction quality. The WS group performs the copying task significantly better in the Deferred Copy condition than in the Direct Copy condition, while the TD group shows no significant difference

Discussion: The “visual conflict” hypothesis

We propose a “visual conflict” hypothesis to explain these results. We suggest that during a direct-copying task, the fact that children with WS continually refer to the local elements of the physically-present target inhibits their ability to reproduce its global form. We believe that three factors may be involved in their poorer performance in the copying task when the target remains present. These are:

- i) Their frequently referring to the physically-present image combined with their over-focusing on its local elements produces a refreshing of these local components in memory, thus causing a conflict with the global image held in memory. (We know this global image exists in memory because of the good performance of children with WS on recognition tasks);
- ii) Their difficulties in retaining location information mean that, even if they ultimately perceive all of the local

- components, they cannot reproduce them at their correct locations (Vicari et al., 2003);
- iii) Children with WS might have deficits in global-local feature binding, as indicated by deficits in 40Hz gamma oscillations (Grice et al., 2001; see Singer, 1995; Gray et al., 1989).

The continual reintroduction of local visual features from the physically-present image impedes the system from effectively settling on a binding between the local and global features in memory. While these data are not consistent with Vicari et al.’s (1996) findings for the *Key Figure* test, Vicari et al. used a considerably longer delay before reproduction (10min). This would have engaged LT memory and might be the cause of the different results.

In short, a “gestalt” perception of a figure held in memory might be easier for children with WS to reproduce because there is less visual interference created by the physical presence of local components of the original image.

General Discussion and Future Work

A number of experiments that are part of the research program presented here still remain to be done. These involve direct copying of movement-enhanced stimuli and recognition of stimuli (both movement-enhanced and static) while the target stimuli remains present during the recognition task. The experimental conditions that remain to be explored are shown in Table 1.

Table 1. Experiments still to be done (marked with a “?”)

	Reproduction (copying)		Recognition	
	Movement enhanced	Static	Movement enhanced	Static
Target present	?	Large deficit	?	?
Target absent	?	Average deficit	No deficit	No deficit

Conclusions

We have presented a series of initial results and computational simulations that are part of a larger research program to better understand visuo-spatial processing deficits in children with WS. A what-where SRN connectionist model of their image-reproduction performance was presented. We consider this to be preliminary work that shows that under a reasonable implementation, the inability-to-locally-disengage would hurt a systems ability to simultaneously encode local and global levels of organization. More than anything else, this simple model represents a dialog between computational modeling and empirical studies. The goal of the model presented here is to force specification of a vague hypothesis (inability-to-locally-disengage) and establish the viability of this hypothesis. We do this by showing that the model can capture the figure-production performance of TD

children, and then, by manipulating a single attentional focus parameter; it can also capture, at least qualitatively, the figure-production performance of children with WS. The fact that the current model is able to do this helps to establish the viability of the disengagement hypothesis. At least one clear prediction derives from the present model — namely, that by artificially provoking local disengagement, reproduction of the target by children with WS should improve. Future work will be designed to determine to what extent a model of this type can capture children’s deferred-copy/direct-copy performances.

Given the difference in reproduction and recognition tasks, we also explored WS performance on recognition tasks. To this end, we developed and used a set of novel movement-enhanced stimuli designed to break the putative over-focusing by children with WS on local elements of global figures. Our results show that the performance of the WS group on these tasks did not differ significantly from that of TD children. This is an unusual finding when exploring these children’s visuo-spatial capabilities. Finally, we present empirical results showing that, in image-reproduction tasks, the performance of individuals with WS is better if the target image does not remain present during figure reproduction, whereas no significant difference was found in chronologically age-matched controls. We suggest a “visual conflict” hypothesis to explain these data. We conclude with a number of future directions in order to complete this program of research.

Acknowledgments

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