Neuropsychologia 48 (2010) 4117–4124

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Visual search performance in the autism spectrum II: The radial frequency search task with additional segmentation cues

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ARTICLE INFO

Article history:
Received 30 April 2010
Received in revised form
10 September 2010
Accepted 2 October 2010
Available online 12 October 2010

Keywords:
Autism-spectrum Quotient
Radial frequency patterns
Visual search
Segmentation
Embedded Figures Test
Visual processing

ABSTRACT

The Embedded Figures Test (EFT) requires detecting a shape within a complex background and individuals with autism or high Autism-spectrum Quotient (AQ) scores are faster and more accurate on this task than controls. This research aimed to uncover the visual processes producing this difference. Previously we developed a search task using radial frequency (RF) patterns with controllable amounts of target/distracter overlap on which high AQ participants showed more efficient search than low AQ observers. The current study extended the design of this search task by adding two lines which traverse the display on random paths sometimes intersecting target/distracters, other times passing between them. As with the EFT, these lines segment and group the display in ways that are task irrelevant. We tested two new groups of observers and found that while RF search was slowed by the addition of segmenting lines for both groups, the high AQ group retained a consistent search advantage (reflected in a shallower gradient for reaction time as a function of set size) over the low AQ group. Further, the high AQ group were significantly faster and more accurate on the EFT compared to the low AQ group. That is, the results from the present RF search task demonstrate that segmentation and grouping created by intersecting lines does not further differentiate the groups and is therefore unlikely to be a critical factor underlying the EFT performance difference. However, once again, we found that superior EFT performance was associated with shallower gradients on the RF search task.

Autism is a developmental disorder characterised by difficulties in social relations, poor language development and restricted patterns of behaviour (American Psychiatric Association, 2000). However, individuals with autism also demonstrate enhanced performance in comparison to matched controls on simple visual search tasks that require detecting a target set among distracters (Jarrold, Gilchrist, & Bender, 2005; O'Riordan & Plaisted, 2001; Riordan, Plaisted, Driver, & Baron-Cohen, 2001; O'Riordan, 2004; Plaisted, O'Riordan, & Baron-Cohen, 1998; Simmons et al., 2009). A similar advantage has been reported for the more complex Embedded Figures Test (EFT; Witkin, Oltman, Raskin, & Karp, 1971) which requires detecting a simple target shape which is hidden or 'embedded' within a more complex stimulus. Individuals with autism, as well as those with high levels of autistic-like traits – as measured by the Autism-spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) – are faster and more accurate on the EFT than controls (Almeida, Dickinson, Maybery, Badcock, & Badcock, 2010; Jonge, Kemner, & van Engeland, 2006; Grinter, Van Beek, Maybery, & Badcock, 2009; Jarrold et al., 2005; Jolliffe & Baron-Cohen, 1997; Morgan, Maybery, & Durkin, 2003; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Pellicano, Maybery, Durkin, & Maley, 2006; Ropar & Mitchell, 2001; Shah & Frith, 1983).

We have recently started to examine visual properties in the EFT that underpin superior performance by those with a high AQ (Almeida et al., 2010). We created a search task employing radial frequency (RF) patterns, which are circular, closed-contour patterns systematically deformed by varying the radius as a function of polar angle using a sine function to create a specified number of cycles of modulation (see Fig. 1; Bell & Badcock, 2009; Loffler, Wilson, & Wilkinson, 2003). These patterns were chosen as stimuli for their ability to represent simple shapes, their mathematical properties (which enable systematic manipulation), and the availability of evidence as to how they are processed by the visual system (Bell & Badcock, 2008; Loffler, 2008; Loffler et al., 2003; Poirier &

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doi:10.1016/j.neuropsychologia.2010.10.009

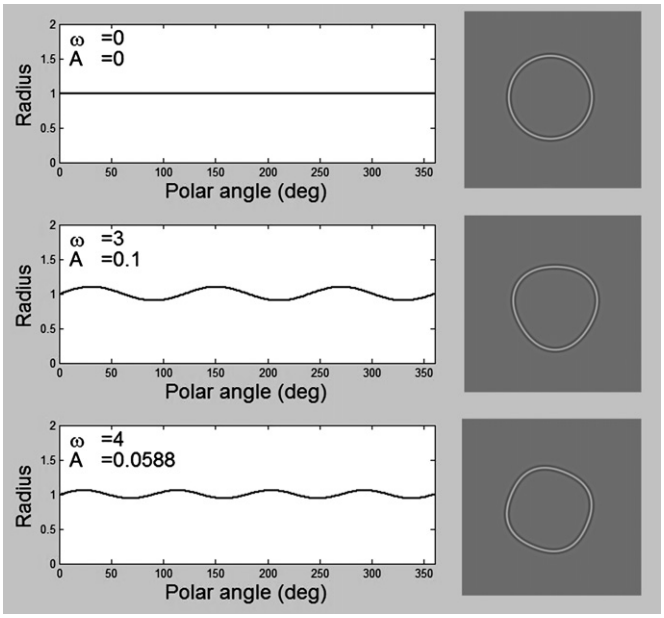

Fig. 1. Examples of three RF patterns (RF0, RF3, and RF4, from top to bottom respectively). The left hand column shows the radius as a function of polar angle while the right hand column shows the resulting RF pattern.

Wilson, 2006). Using these patterns, the RF search task involves detecting a target RF3 (triangular shape) amongst a background of distracter RF4 (square-shaped) patterns, which is similar to the process of finding target patterns amongst distracters in the EFT. Given that other shapes often overlap the simple shape in the EFT, overlap was also introduced into the RF search task, such that the target was either spatially discrete (singles condition), or linked with one other (pairs condition), or three other (quads condition) distracter RF patterns. The high AQ group showed superior performance on this new RF search task compared to the low AQ group, producing a significantly shallower slope for reaction time (RT) as a function of element set size (SS) in all three conditions. Interestingly, the difference in performance between the groups (the ratio of the gradients) was not more pronounced in the quads condition which contained the most overlap, suggesting that such overlap in the EFT does not contribute to the differences in performance between AQ groups (Almeida et al., 2010).

While the previous work demonstrates that overlap of pattern elements is not critical in differentiating high and low AQ groups, differences between these groups in performance on the EFT have been repeatedly observed (Almeida et al., 2010; Grinter, Maybery et al., 2009; Grinter, Van Beek et al., 2009; Russell-Smith, Maybery, & Bayliss, 2010). Because the composition of the stimuli in the EFT has not been examined systematically, it is too soon to attribute all of this difference to a simple advantage in speed of search in high AQ individuals. The aim of the current study was, therefore, to examine whether segmentation – rather than overlap – in EFT stimuli contributes to improved performance in high AQ participants. In the previous study (Almeida et al., 2010) observers reported that in the most complex quads condition, they resorted to segmenting the stimulus display into clusters, then searching each cluster (of four RF patterns) until locating the one which contained the target. Thus the rationale in designing the present study was to segment the stimulus display more explicitly, while systematically manipulating the presence and nature of any overlap of stimulus elements. The background which embeds the simple target shape in the EFT always involves the addition of lines which are thought to increase the complexity of the search. The lines either intersect the target, run alongside the contour of the target, or are near the target, but not directly touching it. However in the EFT there is no systematic manipulation of these alternatives. Consequently, we wished to introduce lines in the background display of the RF search task in a controlled manner, to determine whether this additional segmentation cue would provide further discrimination between the two groups.

The addition of lines could impact performance in at least two ways. The first is by providing spurious segmentation cues that may fragment the target or the display in an unhelpful manner as described above (Spillmann & Ehrenstein, 2004). Such segmentation would be evidenced by an increase in slope, as observed in the previous study (Almeida et al., 2010), where observers would be required to examine each segment in turn. The second is by introducing clutter into the display which may affect performance (evidenced by an increase in intercept) through either masking or crowding. A recent study investigated the influence of clutter on search performance in real-world scenes (Henderson, Chanceaux, & Smith, 2009). Henderson et al. (2009) examined search behaviour as a function of three computed measures of clutter: feature congestion, edge density, and sub-band entropy. They demonstrated that clutter correlated with reduced search efficiency, reflected by longer search times and increased search failure, and with increased eye movement behaviour during search. They also observed that edge density was the only clutter measure to significantly correlate with all dependent measures derived from search behaviour. Interestingly, in this measure of clutter, the edges of the scene are highlighted, producing an image of the edges that appear as a configuration of *lines* which represent edge density (see Fig. 2). They concluded that clutter may serve as an image-based proxy for search SS in real-world scenes (Henderson et al., 2009) with greater clutter requiring longer searches. Wolfe and colleagues created a task in which a known target was presented amongst distracters that closely resembled the target and these stimuli were superimposed on a cluttered scene (Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002). The task involved searching for a yellow "*T*" amongst distracter yellow "*L*"s, which was all superimposed on backgrounds which involved clutter of varied complexity (i.e., an empty, neat, or messy desk). They found that the clutter caused an increase in the intercept, but not in the slope of the search function, consistent with the finding of Henderson et al. (2009) that clutter acts as an addition to SS, producing an overall increase in intercept. If the lines are acting as clutter in the present study, we would predict an increase in the intercept for all conditions containing lines as each had the same approximate addition of clutter (i.e., same average line length).

The present study involved detection of a known target (RF3) from amongst a background of distracter patterns (RF4s) with the addition of lines to the background to introduce clutter and alter segmentation cues. The aim of the study was to ascertain whether the additional lines further differentiate the two groups, and if so, whether the type of segmentation matters. The lines touch a surrounding box at each end and pass through the image on a pseudorandom path with some specific constraints. Thus the lines divide the total stimulus into segments. We wished to know whether the high AQ individuals would be better at de-cluttering (evidenced by a relatively higher increase in intercept for the low AQ group as compared with the high AQ group) in addition to being efficient searchers as previously observed (Almeida et al., 2010; Jarrold et al., 2005; O'Riordan, 2004; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). We aimed to determine the influence of segmentation by introducing clutter at a specific level (two additional lines) and varying the impact of segmentation on the whole stimulus, distracters, or targets respectively. Again, we wished to determine whether segmentation would affect the groups differentially. Finally, as the purpose of the addition of lines to the RF search task was to increase similarity to the task at hand in the EFT,