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Dyslexia and the assessment of visual attention.

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Abstract

Visual stream segregation has been proposed as a method to measure visual attention in dyslexia. Another task proposed to do this is the line-motion illusion. Both tasks, it is observed, can be carried out with spatially distributed stimuli. This, however, appears inconsistent with these tasks being linked specifically to attentional processes since this would require them to spatially focus cognitive resources. Also, both line-motion and visual stream segregation involve the perception of movement raising the possibility that what is actually measured by these tasks is not attention but some aspect of motion perception.

Key words: Attention, dyslexia, visual stream segregation, motion, apparent motion, line-motion illusion.

1. Introduction

To what extent dyslexia is linked to an attentional deficiency is a critical question for understanding this condition and has, as a result, been the subject of considerable research and debate (e.g., Hari and Renvall 2001; Skottun and Skoyles 2007b; Facoetti et al. 2008). As a result, it is important to find reliably means to assess the attentional capacities of dyslexic individuals. As far as visual attention is concerned, a number of different tests have been proposed such as, e.g. visual search (Vidyasagar and Pammer 1999; see Skottun and Skoyles 2007a for a discussion), and the effect of cues (Roach and Hogben 2004), Two further ones are the line-motion illusion (Steinman et al. 1998), and visual stream segregation.

A notable issue in regard to the last two is that visual attention involves the spatial focusing of cognitive resources (i.e. a concentration on a focus of attention) making vision more accurate or more sensitive at one location (or at most a few locations) as compared to other locations (Posner et al. 1980; Luck et al. 1994). This is, for instance, why the use of precues as to the spatial location of targets can be used to explore visual attention (Posner et al., 1980). Attention, as a consequence, is not generally associated with perceptual effects which are distributed over large parts of the visual field, or effects occurring simultaneously at many different locations. In the present report the implications of this are examined as they apply to the line-motion illusion and visual stream segregation.

2. Line-motion illusion

The line-motion illusion is a task that has been claimed to depend on attention (Hikosaka et al. 1993) but which is judged now unlikely to do so (Skottun and Skoyles

2006b). This illusion is typically created by presenting a dot followed by a line at an adjacent location. What is perceived is that the line does not appear all at once but rather that it appears to "grow" in the direction away from the dot. This was originally interpreted as being a result of attention (Hikosaka et al. 1993) as it was argued that the dot directed attention to its location and that this attention caused stimuli in the vicinity of the dot to be processed faster. The difference in processing speed, it was hypothesized, caused the line to appear first in areas near the dot, and only later at locations farther away. The line-motion illusion has, like visual stream segregation more recently, been proposed as a test of attention in research upon dyslexia (Steinman et al. 1998).

However, it has been demonstrated that the line-motion illusion can be observed simultaneously with stimuli at many spatially distributed locations. Faubert and Grunau (1995) found that when a line is preceded by two dots, one located near each end of the line, the line is seen to grow from both ends towards the middle. This would require that attention is split in two and that the amount of attention devoted to the area between the two spots is smaller than the amount of attention directed at them. Kawahara et al. (1996) further found that the line-motion illusion may be obtained with as many as eight simultaneously presented dot-line pairs. These observations are difficult to reconcile with an attentional process that focuses cognitive resources onto a specific location (Skottun and Skoyles 2006b).

3. Visual stream segregation

Visual stream segregation is generated by presenting subjects with two spatially separated dots (Lallier et al. 2009). The dots are alternated in time and the stimulus onset asynchrony (SOA) is varied, that is to say, the rate of alternation is changed. Varying the SOA gives rise to two different kinds of percepts: At long SOAs (i.e., at low alteration rates) there is a perception of one dot moving back and forth (see Fig. 1 of Lallier et al. 2009). This is referred to as the "one stream" percept. At shorter SOAs (i.e. at higher alteration rates) two continuous, and spatially, separate dots instead are seen. This is referred to as the "two streams" percept. Lallier et al. (2009) measured the SOA at which the percept switched from being a "one stream" percept to becoming a "two streams" percept. They found that this transition value was higher for some dyslexic individuals than for the control group. This the authors interpreted as evidence for "sluggish attentional shifting" on the part of the dyslexic individuals.

However, rather than using a single dot pair, as did Lallier et al. (2009), the same task can be carried out with several pairs of alternating dots (see Figs. 1 and 2). When this is done several spatially separate and simultaneous "one steam" percepts can be seen. In our stimuli this can be obtained with five spatially separate pairs of dots (Fig. 1) which give five simultaneous "one stream" percepts (Fig. 2A). This is analogous with Kawahara et al. (1996) generating the line-motion illusion with several line-motion stimuli. Moreover, by alternating the stimuli sufficiently fast (i.e. by having SOAs adequately short), the alternating dots of each pair appear as two continuous dots. This gives rise to five spatially separate and simultaneous "two streams" percepts, that is, ten stationary dots are seen (Fig. 2B). Further, since "two streams" percepts can be obtained at high alternating rates and "one stream" percepts at low alternating rates, there exists also an alternating rate (i.e. an SOA) at which the percept switches from a set of one stream percepts to a set of two streams percepts.

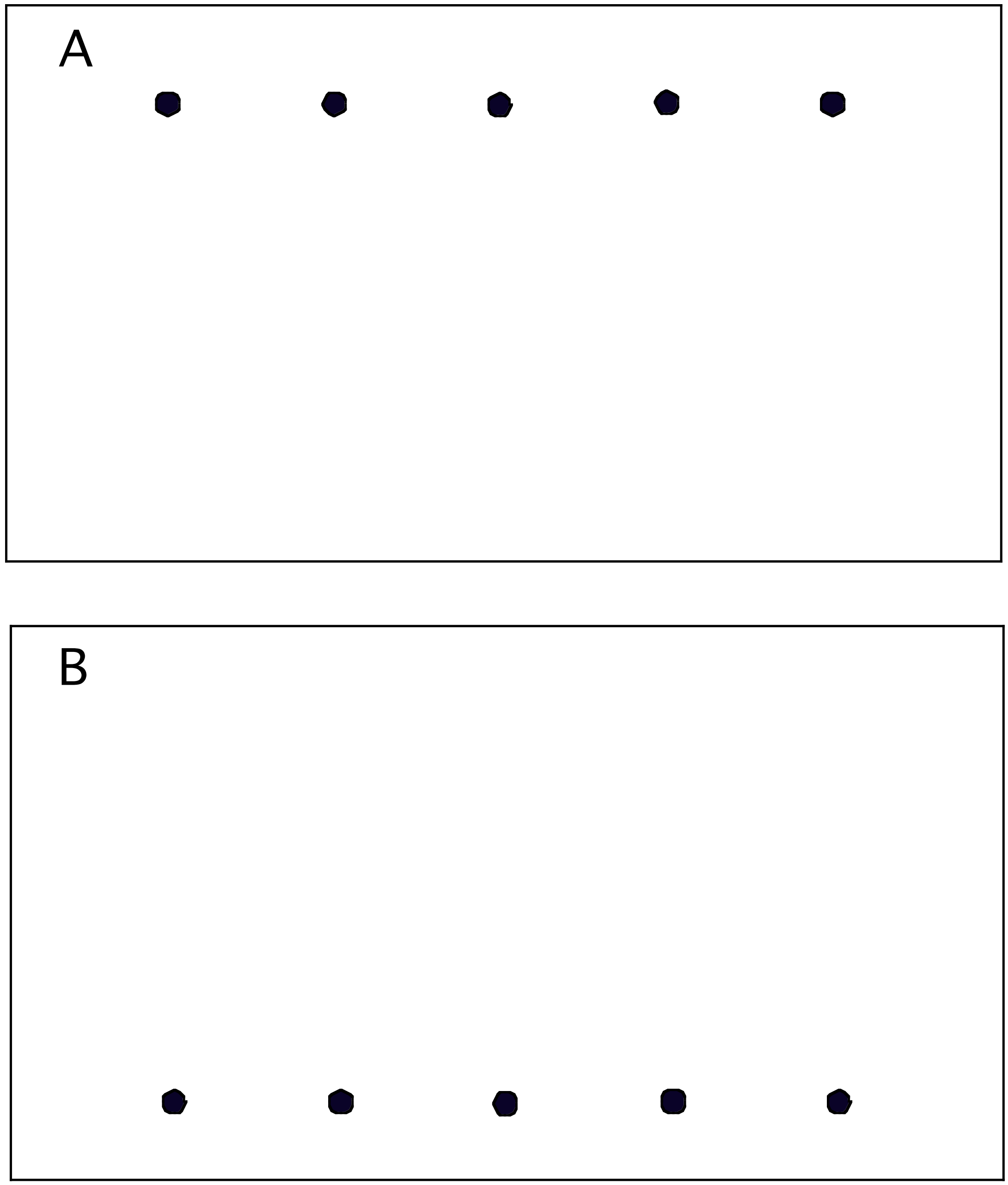

Figure 1. Extended stimuli that can be used to demonstrate "one stream" and "two streams" percepts. In panel A, there are five black dots in a row just below the top of the frame. In the stimulus in panel B, there are five dots near the lower edge of the stimulus frame. When carrying out the tests, the two stimuli are alternated. Depending on the alternating rate, this can give rise to one stream or two streams percepts (see Fig. 2). Typical viewing distance was 57 cm. The width of the row of dots was 16.3 deg and the positional difference between the dots in Stim. 1 and Stim. 2 was 11.6 deg. However, the described perceptual effects do not appear to be highly dependent upon spatial parameters.

Thus, the SOA for transitions from "one stream" percepts to "two streams" percepts can be determined with spatially extended stimuli having multiple dot pairs. However, since the transition can be determined with a spatially extended stimulus, this suggests that spatially focused attention is not a determining factor for the SOA at which the percept switches from one stream to two streams.

Could this be due to the involvement of attention of a non-spatial kind? This seems unlikely since it is uncertain if, or to what extent, non-spatial attention may generate the observed types of perceptual effects. For instance, Posner et al. (1980) found that information about stimulus location improves performance whereas it does not with information about its form. Also, any kind of non-spatial attention would entail that the attention underlying visual stream segregation would be of a fundamentally different kind from that postulated for the line-motion illusion. This is because it was precisely the spatial focusing of attention that was hypothesized to provide the underlying process for this illusion.

It might be argued that attention can be assessed by examining the difference between results obtained with a single pair of dots and the results obtained with multiple dot pairs. But this creates its own difficulties. First, the possibility exists that there may not be any difference between the results obtained with a single pair and those obtained with multiple dot pairs. Second, even if such a difference were to exist, the results would not only differ with regard to the degree with which they rely upon attention but also with regard to factors such as stimulus strength and the degree to which they depend on spatial integration. As a result, these other factors rather than attention might be responsible for any differences observed. Thus, to attribute to attention the difference between the results

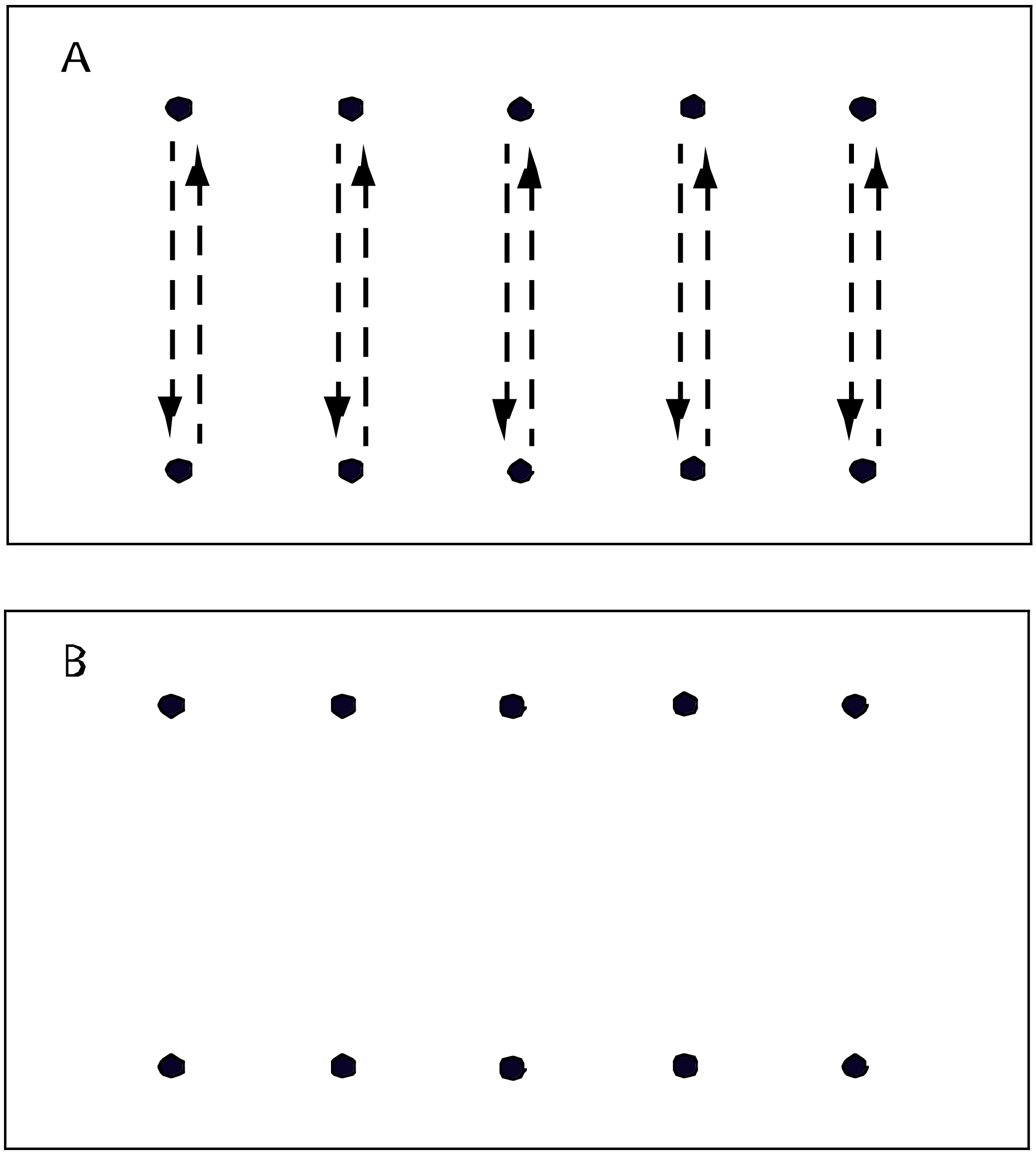

Figure 2. Illustrations of the two different possible percepts that can be obtained with the stimuli in Fig 1. (A) When the alternating rate is low the dots (in the present example, five dots) are seen to all be moving back and forth. This corresponds to several "one stream" percepts or one spatially extended one stream percept. (B) When the two stimuli are alternated rapidly two sets of stationary dots are seen. This corresponds to the "two streams" percept. In the present example this corresponds to ten (more or less) stationary dots. Since "one stream" and "two streams" percepts can be obtained with spatially extended stimuli, it is difficult to link these stimuli to attention, since attention would involve some degree of spatial concentration of resources. An animation of the one-stream stimulus with multiple dots can be seen at http://upload.wikimedia.org/wikipedia/commons/5/5e/OneStream200ms.gif. (Line motion with multiple dot-line pairs can be seen at http://upload.wikimedia.org/wikipedia/commons/b/b0/LineMotion200_ms.gif.)

obtained with a single pair of dots and those obtained with multiple pairs is far from obvious or straightforward.

4. Visual motion

The line-motion illusion is related to visual motion perception since it is based on the perception of movement. In fact, it has been suggested that this illusion is a case of apparent motion (Grunau & Faubert 1994; Kawahara et al. 1996; Downing & Treisman 1997; Grunau et al., 1996). In support of this is the finding that the direction of the illusory movement can be reversed when the spot is presented after the line (Downing and Treisman 1997; Eagleman and Sejnowski 2003).

In the case of visual stream segregation, the one stream percept is related to motion perception since this percept is obtained when the dot is seen as moving back and forth (see Fig. 1 of Lallier et al. 2009). In the case of the two streams percept, on the other hand, there is no perception of movement as the two dots are perceived as stationary. This suggests therefore that one stream perception occurs under conditions when apparent motion is obtained and that the two streams percept occurs when no motion is seen.

The suggestion that visual stream segregation may be linked to motion perception indicates for this reason a need for caution in interpreting the results in terms of attentional factors. This applies particularly to data obtained from individuals with reading difficulties because data exist linking dyslexia to deficiencies in the ability to perceive visual motion (see, e.g., Skottun and Skoyles 2006a, for a review). It is therefore possible that the difference between dyslexic subjects and controls observed both with the line-motion task and with the visual stream segregation task could be due (wholly or in part) to a reduced ability to perceive motion on the part of the dyslexic subjects. Until this possibility has been ruled out visual stream segregation ought not be used to test attention since it is inappropriate to employ as a test of attention a task which potentially involves a process on which dyslexic individuals are known, or widely held, to be deficient.

5. General discussion

The above considerations indicate that both line-motion illusion and visual stream segregation can be obtained with multiple stimuli. Because attention involves, at least to some degree, spatial concentration of resources, this is inconsistent with attention being the critical factor determining task performance.

One potential objection might be that that attention can be divided--for instance McMains and Somers (2004) found it possible to attend to two spots simultaneously. This however would face three issues:

(1) According to the hypotheses both visual stream segregation and line-motion depend upon spatially localized rather than just divided attention. In the case of the line-motion illusion this, it was hypothesized, is generated by spatial differences in attention. (In fact, the title of the initial paper of Hikosaka et al., 1993, was precisely “Focal visual attention produces illusory temporal order and motion sensation".) In the case of visual stream segregation, Lallier et al., (2009) described the attentional factors in terms of attentional "shifting" and "shifting" of the "attentional focus". This entails some degree of spatial focusing of attention. Thus, the hypothetical links between these tasks and attention assume that attention is not uniformly distributed.

(2) VanRullen et al. (2007) found that what appears to be concurrent focusing of

multiple targets is not actually this but rather is a matter of rapid switching of attention between locations. They estimated that attention can encompass seven locations per second with such switching. That means that each location is attended to for 143 ms. In the case of visual stream segregation this duration however is longer than the thresholds duration of 104 ms for visual stream segregation (for controls). In the present examination multiple one stream percepts were obtained with frame rates of roughly 200 ms. As a result, both one stream percepts and two streams percepts can be obtained within time durations too short for attending to multiple locations. A similar inconsistency occurs for line motion illusion. Kawahara et al. (1996) obtained the strongest illusion (least percentage errors in their tests) with multiple dot-line pairs when the interstimulus interval (ISI) was 0 ms and found that the illusion was reduced in strength at longer ISIs (e.g. 400 ms). This is essentially the opposite of what would be predicted for an attentional effect based on the findings of VanRullen et al. (2007) where a longer duration would allow better opportunity to switch attention location and so create a stronger illusion in the case of multiple stimuli.

(3) Jans et al. (2010) found that dividing attention is not a simple faculty but one that depends upon a skill that requires training. In contrast, the line-motion illusion and visual stream segregation (i.e. both one stream percepts and two streams percepts) are readily obtained with multiple targets without any practice.

These points suggest problems exist in attributing performance on visual stream segregation and lime-motion illusion obtained with multiple spatially distributed stimuli to spatially divided attention. And since it is difficult to attribute these phenomena to attention in the case of multiple stimuli it is also difficult to attribute them to attention in the case of single stimuli.

Visual stream perception and the line motion illusion it might be objected could still potentially involve or reflect attentional factors. However in order for a task to serve as a test of attention it is not sufficient that the task *could potentially* involve attention. Rather a compelling reason needs to exist for attributing the performance limiting factor to attention. In the case of both the line motion illusion and visual stream segregation no grounds for this exist. Moreover, most psychophysical tasks require subjects to pay attention to some degree, and this is likely to also be the case with the line-motion illusion and visual stream segmentations. But as such, visual stream segregation and line-motion illusion would not be different from tasks such as contrast sensitivity and Vernier acuity. Thus it is difficult to link with any confidence line-motion illusion and visual stream segregation to attention in a way that makes them dependent specifically on attention in a manner different from that found in most other psychophysical tasks. The existence of some unspecific involvement of attention in a task is not by itself sufficient to make it one that could be used as a test of attention.

In conclusion, in order for some psychophysical task to be employed as a test of attentional capabilities, it is required that the task in question is either consistent with attention being focused on some spatial locus, or, if the task can be carried out with multiple or distributed stimuli, it needs to be shown that this is consistent with what is known about spatially divided attention. In the case of both visual stream segregation and line-motion illusion neither of these requirements are met. Thus to use visual stream segregation and line-motion illusion to asses attention faces obstacles. This is particularly so in the case of individuals with reading problems since both of these tasks involve perception of motion--an area of visual perception in which dyslexic individuals have been shown to be deficient.

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