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Visual processing asymmetries in change detection

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Abstract. Change detection is critically dependent on attentional mechanisms. However, the relation between an asymmetrical distribution of visuo-spatial attention and the detection of changes in visual scenes is not clear. Spatial tasks are known to induce a stronger activation of the right hemisphere. The effects of such visual processing asymmetries induced by a spatial task on change detection were investigated. When required to detect changes in the left and in the right visual fields, participants were significantly faster in detecting changes on the left than on the right. Importantly, this left-side superiority in change detection is not influenced by inspection time, suggesting a critical role of visual processing benefit for the left visual field.

1 Introduction

Even though the detection of changes in visual scenes is a vital ability (see Rensink 2002, for a detailed review), human observers are often astonishingly blind to even large changes (see Simons 2000; Simons and Rensink 2005, for reviews on change blindness). Change blindness has been shown to arise from the visual occlusion of change signals during eye blinks (O'Regan et al 2000), saccades (eg Henderson and Hollingworth 1999), and blank screens between scenes (Rensink et al 1997). If no occluder is presented, change detection is easy, owing to the transients induced by the change. Observers are not only blind to abrupt changes covered by occluders, but also to changes which occur gradually (Simons et al 2000). In this case, the lack of a transient weakens the change signal.

Attention has been shown to play a crucial role in change perception: while changes in the attended part of a visual scene are detected with ease, diverting the observers' attention away from the change signal impairs the detection of changes (Rensink et al 1997). O'Regan et al (1999) demonstrated that mudsplashes displayed simultaneously with changes in the visual scene cause change blindness. This finding is another indication that attention is crucial in change perception since mudsplashes draw observers' attention away from changes and change blindness occurs. Conversely, Scholl (2000) reported an attenuation of change blindness when attention is drawn to the change by an exogenous cue. Change blindness is also related to the phenomenon of inattentional blindness, where observers are unable to see even unexpected or clearly visible objects under diverted-attention conditions (eg Simons and Chabris 1999).

Observers often show a leftward bias in the allocation of attention while performing visuo-spatial tasks (eg Cocchini et al 2007; Nicholls et al 1999). However, the effect of this asymmetrical distribution of visuo-spatial attention on the detection of changes in visual scenes is not clear. Hemispatial neglect and pseudoneglect provide two cases where the asymmetrical distribution of visuo-spatial attention plays a role. Neglect patients typically fail to notice stimuli located within the visual field opposite to the brain lesion (eg Heilman and Valenstein 1979; Marshall and Halligan 1988). Neglect may occur after lesions to the right or the left hemisphere, but left hemispatial neglect after right-hemisphere damage is seen more often and is more severe and long-lasting (see Manly 2002, for a review). A common test of hemispatial neglect is the line-bisection task (Jewell and McCourt 2000). Patients with left hemispatial neglect typically bisect horizontal lines to the right of the centre (eg Heilman and Valenstein 1979), whereas neurologically normal observers bisect lines with a small bias to the left—a phenomenon called pseudoneglect (Bowers and Heilman 1980). McCourt and Jewell (1999) reported that the magnitude of the line-bisection error can be modified by stimulus features such as line position, line length, and line aspect ratio, both and similarly in neglect patients and neurologically healthy people. Because of this similarity between patients and the normal population, McCourt and Jewell suggested that both neglect and pseudoneglect should be considered as indicators of hemispheric attentional asymmetries.

A possible explanation for pseudoneglect is provided by the activation-orientation hypothesis (Reuter-Lorenz et al 1990). According to Reuter-Lorenz et al the distribution of attention is biased towards the visual field opposite to the more activated hemisphere. Owing to the spatial nature of a line-bisection task, the right hemisphere is more active than the left hemisphere; therefore, the left visual field receives more attention. Consequently in the line-bisection task attention is focused on the left half of the line with the result of this left half being perceived as longer. To compensate for this asymmetry, the observer places the midpoint of the line to the left of the centre (Reuter-Lorenz et al 1990). Bultitude and Davies (2006) further supported Reuter-Lorenz et al's activation-orientation hypothesis by demonstrating the direct relationship between enhanced visual attention and the bisecting error.

Change detection in a visual scene can be considered a spatial task which might be prone to an asymmetrical distribution of attention. Our aim here is to investigate the relationship between attentional asymmetry and change detection using the flicker paradigm introduced by Rensink et al (1997). We expect that attention in this spatial task will be primarily focused in the left visual field and cause a visual processing benefit compared to the right visual field owing to stronger right-hemispheric activation. Therefore, changes in the left visual field should be detected more rapidly than those occurring in the right visual field. In case change detection varies between the left and right visual fields, we planned to investigate the contribution of the left–right distribution of eye movements to this expected change-detection asymmetry.

2 Experiment 1

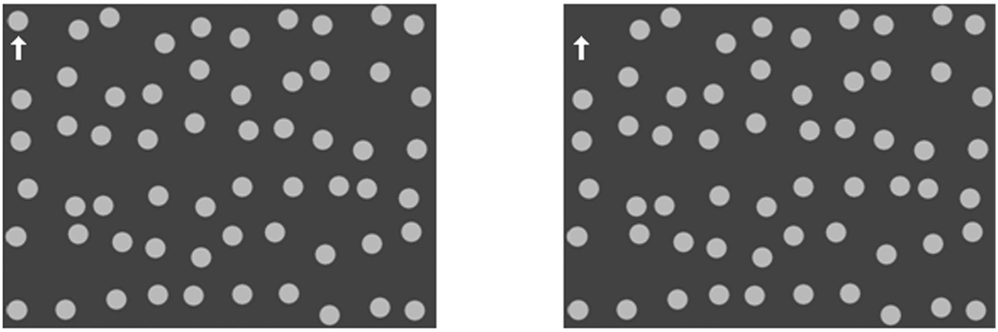
In this experiment we aimed to investigate the influence of an asymmetrical distribution of attention in a spatial change-detection task.

2.1 *Methods*

2.1.1 *Participants.* Twenty undergraduate and graduate students (ten female and ten male) with ages ranging from 19 to 29 years (mean, $M \pm \mathrm{SD} = 23.85 \pm 2.92$ years) participated in the experiment. All participants were right-handed as determined by the Edinburgh Handedness Inventory (Oldfield 1971) and reported normal or corrected-to-normal vision in both eyes.

2.1.2 *Apparatus.* The experiment was run on a PC (Pentium 3.06 GHz with 75 Hz 17-inch monitor) positioned at a distance of 50 cm from the participants' eye level. The screen display subtended about 35 deg (width) by 26 deg (height) of visual angle. Participants' responses were collected by using the computer keyboard and the mouse placed directly in front of them.

2.1.3 *Stimuli.* 60 pairs of 32-bit coloured images were generated for the experiment (with the images being the same for each observer). The images consisted of 60 yellow circles (radius $= 1.8°$; $RGB =[192, 192, 0]$) on a grey background ($RGB = [64, 64, 64]$).



Original image Modified image

Figure 1. An example stimulus in experiment 1. The circles were shown in yellow on a grey background. The arrow indicates the change, but was not present during the experiment.

Circles were positioned semi-randomly so that they were non-overlapping and distributed evenly across the fifteen target-screen locations (described later). Each pair of images consisted of an original image and a modified image in which one of the circles of the original image was removed. An example of a stimulus pair is shown in figure 1.

2.1.4 *Procedure.* Participants were seated in front of the computer screen with a chin-rest to keep head position and viewing distance constant. Before the experiment, participants were informed that they were going to see a series of images containing yellow circles one of which would disappear and had to be detected by them. Participants were asked to press the space bar on the keyboard immediately after they had seen the change. Following a 100 ms mask, participants were asked to click on the changed circle with the mouse. After subjects indicated the detection of the change, the fixation point of next trial was displayed on the screen.

All participants were given two practice trials to familiarise themselves with the task. In each trial the original and modified images were separated by a grey blank screen ($RGB = [192, 192, 192]$) and alternated repeatedly, resulting in a flicker presentation as described by Rensink et al (1997). The sequence of 60 image pairs was determined randomly for each participant. After presentation of a fixation point for 2 s, the images were displayed one after the other for 300 ms, interleaved with a blank screen of 100 ms. This cycle of presentation continued until the participants detected the change or 60 s elapsed in which case the trial was recorded as a missed change.(1) Reaction times were recorded in milliseconds.

Changes could happen at 15 different locations (figure 2), with each location being tested 4 times. The disappearing circle was determined randomly for each location.

2.2 *Results*

To compare performance in the left and right hemifields, the locations L1 – L6 and L10 – L15 were averaged to derive a mean reaction time for the left and right visual field, respectively (see figure 2). A paired-sample t-test was conducted to compare participants' mean reaction times for the detection of the changes occurring in the left and right visual fields. The analysis revealed a significant difference in reaction times between left and right visual fields with participants detecting changes to the left visual field ($M \pm \mathrm{SE} = 7591 \pm 577$ ms) faster than changes occurring in the right visual field ($M \pm \mathrm{SE} = 9014 \pm 600$ ms), $t_{19} = 2.80$, $p = 0.011$ (figure 3).

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(1) 0.25% of the total responses (1200 responses = number of trials × number of participants) were recorded as a missed change. None of the participants missed changes more than once. 3.08% of the total responses were recorded as an incorrect detection. None of the participants gave more than 4 incorrect responses.

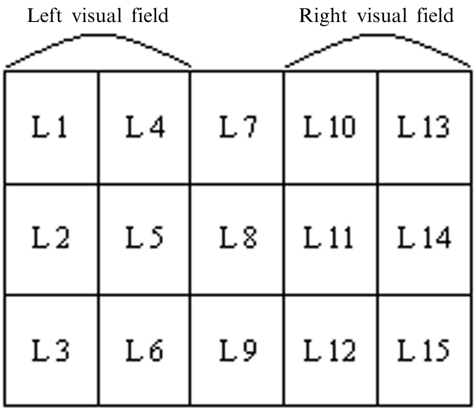

Figure 2. Locations of the changes (L = location).

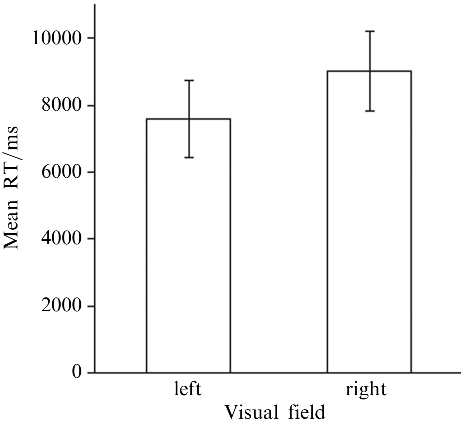

Figure 3. Mean reaction time needed to detect the changes in the left and right visual fields in experiment 1. Error bars indicate 95% confidence interval.

3 Experiment 2

In experiment 2, we attempted to examine the role of eye movements in the leftward bias in the spatial change-detection task. A shorter version of experiment 1 was conducted with the SR Research EyeLink II eye-tracker system to record eye movements.

3.1 *Methods*

3.1.1 *Participants.* Fourteen undergraduate and graduate students (eight female and six male) with ages ranging from 17 to 30 years ($M \pm \mathrm{SD} = 23.14 \pm 3.9$ years) participated in the experiment. All participants were right-handed and reported normal or corrected-to-normal vision in both eyes. Participants' handedness was determined by the Edinburgh Handedness Inventory (Oldfield 1971).

3.1.2 *Apparatus.* The apparatus was the same as in experiment 1. In addition, the SR Research EyeLink II eye-tracking system was used to record eye movements.

3.1.3 *Stimuli.* 30 image pairs from the stimulus set of experiment 1 were used in this experiment.

3.1.4 *Procedure.* Eye positions were recorded monocularly and sampled at 250 Hz. Head position was recorded to compensate eye movements for head motion. In order to correct participants' eye positions before each experimental run, calibration and validation procedures were performed by using a nine-point grid with the target points being displayed in a random sequence. Only participants whose eye positions were calibrated and validated successfully proceeded with the experiment.

Stimulus presentation was similar to that in experiment 1, except for an additional drift-correction run. At the beginning of each trial a drift correction was performed to control for changes in the eye-tracker position. At the same time, the drift-correction target also served as a fixation point. The recording of eye movements was initiated automatically with the onset of the first image pair and stopped with the participants' response on each trial.

3.2 *Results*

3.2.1 *Reaction time.* In accordance with the first experiment, participants detected changes to the left visual field ($M \pm \mathrm{SE} = 6482 \pm 731$ ms) more rapidly than changes occurring in the right visual field ($M \pm \mathrm{SE} = 7626 \pm 814$ ms), $t_{13} = 2.39$, $p = 0.033$.

3.2.2 *Eye-movement data.* Three parameters were analysed for correct-response(2) trials to compare the eye-movement patterns of the left and right eyes: the total duration of fixations, the total number of fixations, and the end-point of the first saccade on each trial.

The mean time a participant was looking at the left and right sides of the screen was computed for each trial by summing the duration of all fixations to the left and to the right in correct-response trials. The mean looking time was not significantly different for the left ($M \pm \mathrm{SE} = 6583 \pm 861$ ms) and right ($M \pm \mathrm{SE} = 6339 \pm 651$ ms) visual fields (locations except L7, L8, L9; see figure 2), $t_{13} = 0.420$, $p = 0.681$.

There was no significant difference in the mean number of fixations to the left ($M \pm \mathrm{SE} = 20.44 \pm 3.25$) and right ($M \pm \mathrm{SE} = 18.96 \pm 2.38$) visual fields, $t_{13} = 0.750$, $p = 0.467$ (figure 4).

To find out whether the participants tended to start to scan the screen from a particular visual field, the percentage of each participant's first saccades which ended on the left half of an image was computed ($M \pm \mathrm{SE} = 67.69\% \pm 4.91\%$). The one-sample t-test (test mean: 50) indicated that participants usually started to search the display from the left side, $t_{13} = 3.6$, $p = 0.003$.

To analyse whether changes on the left or right are more likely to be detected when the first saccade was to the left or to the right, mean reaction times were computed for the following trials: change on the left-first saccade to the left (CL-FSL), change on the left-first saccade to the right (CL-FSR), change on the right-first saccade to the left (CR-FSL), change on the right-first saccade to the right (CR-FSR). The t-tests showed that there was no significant difference in mean reaction times between CL-FSL ($M \pm \mathrm{SE} = 6471 \pm 742$ ms) and CL-FSR ($M \pm \mathrm{SE} = 7246 \pm 1405$ ms) trials, $t_{11} = 0.737$, $p = 0.477$).(3) Similarly, no significant differences between CR-FSL ($M \pm \mathrm{SE} = 7402 \pm 1030$ ms) and CR-FSR ($M \pm \mathrm{SE} = 7733 \pm 1339$ ms) trials were observed, $t_{13} = 0.192$, $p = 0.851$.

4 General discussion

The results of experiment 1 confirmed our hypothesis of a distinct left visual field advantage in detecting changes. This left visual field superiority suggests the existence of a leftward attentional bias in a spatial change-detection task. As in experiment 1, observers were better in detecting changes to the left visual field in experiment 2. However, we did not find any difference in observers' fixation times and number of fixations between left and right halves of the screen. This suggests that, in this spatial task, there is a visual processing benefit for the left visual field that increases change-detection probability on the left side.

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(2) 0.48% of the total responses (420 responses = number of trials × number of participants) were recorded as a missed change. None of the participants missed changes more than once. 1.67% of the responses were recorded as an incorrect detection. None of the participants gave more than 3 incorrect responses.

(3) Because two participants did not make any *right-first saccade* in the *change on the left trials*, the number of degrees of freedom is 11 in this analysis.

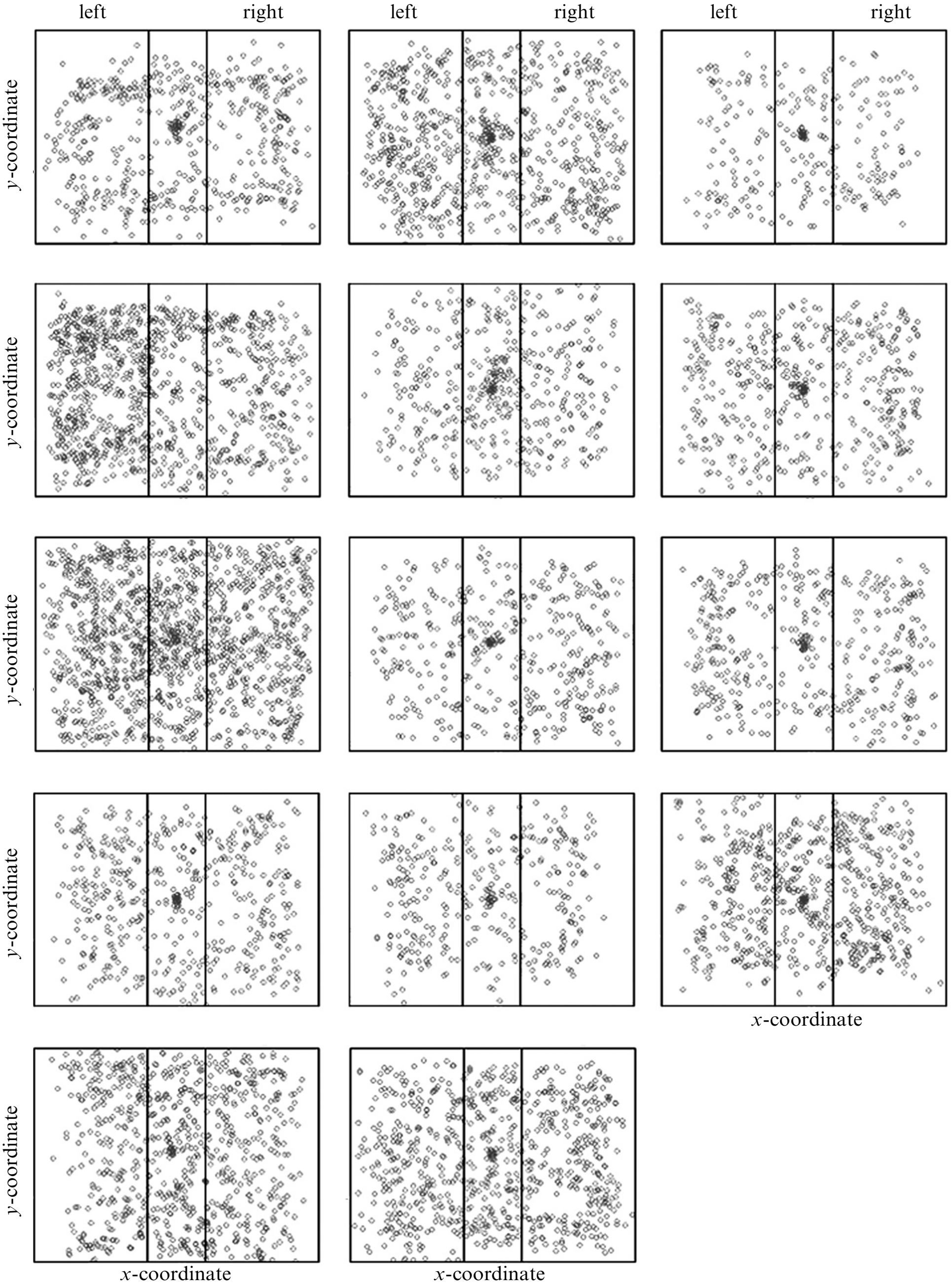

Figure 4. Superimposed fixation positions of each participant for correctly responded trials.

Unlike the inspection time, one aspect of eye movements was different between the left and right visual fields: the participants typically started to search the scene from the left side. This may be the result of reading habits, as all participants were readers of the Latin alphabet. In a meta-analysis, Jewell and McCourt (2000) revealed that scanning direction during line-bisection tasks is an important confounding effect of pseudoneglect, such that left-to-right or right-to-left scanning directions cause leftward or rightward biases, respectively. However, the scanning-direction effect does not imply that pseudoneglect is an artifact of left-to-right scanning. Studies of tachistoscopic line-bisection tests showed that, even when the eye movements were controlled, a systematic leftward bisecting error occurred (eg McCourt and Jewell 1999). Indeed, participants of experiment 2 did not appear to use a systematic left-to-right search strategy, although they usually started to examine the scene from the left. Instead, they seemed to use different search paths on each trial (see sample eye-movement maps in the Appendix). Consequently, a possible left-to-right scanning effect was not a confound for a leftward attentional bias in the second experiment. Additionally, the last *t*-tests point to the fact that faster reaction times in detecting changes on the left are not related to a leftward starting point of the search path.

The leftward superiority in change detection might be explained by two different sets of mechanisms. First, it is in line with the activation-orientation hypothesis (Reuter-Lorenz et al 1990). Reuter-Lorenz et al reported an asymmetry in hemispheric activation during spatial tasks. According to this hypothesis, the distinctly spatial nature of detecting a change in a visual scene in our study may have activated the right hemisphere more than the left hemisphere. This asymmetrical activation may have caused stronger attentional control of the left visual field, leading participants to detect changes in the left visual field more rapidly than those occurring in the right visual field.

Besides this task-driven explanation, the advantage of the left visual field in change detection might also be attributed to a general dominance of the right hemisphere in attentional processing, as suggested by Heilman and Van Den Abell (1980). Such a right-hemispheric dominance of attentional processing may similarly cause a superiority of the left visual field for the detection of changes.

Importantly, we showed that there is no difference in eye movements between the left and right halves of the image, even if there is a left-visual-field advantage in change detection. This finding is especially surprising as eye movements and visual attention are often strongly related (eg Hoffman and Subramaniam 1995). Deubel and Schneider (1996) reported an interaction between attention and saccadic eye movements with the performance of object recognition being best when the eye is directed to the object to be recognised and the performance declines dramatically when the saccade is directed to a different location from the target object. Shepherd et al (1986) found that the generation of an eye movement necessitates a corresponding shift in attention. On the other hand, observers may attend locations they are not fixating (Posner 1980) and looking at the location of a change does not make sure that the change will indeed be detected by the observer (eg Hayhoe et al 1998; O'Regan et al 2000). Therefore, our eye-movement data are in accordance with these suggestions as the eye-movement pattern is similar in the left and right visual fields but change-detection performance is not.

Although observers made comparable eye movements to the left and right halves of the images in our study, more attentional resources might have been allocated to the left visual field, resulting in a more efficient processing of visual input. This enhanced ability to detect visual changes can be attributed to an overall attentional dominance of the right hemisphere or a stronger activation of the right hemisphere induced by the spatial nature of the task. In any case, while the left and the right visual fields provide the same quantity of visual information, the input received from the left visual field is processed more efficiently owing to this right-hemispheric dominance.

Lastly, even if we emphasised the attentional dominance of the right hemisphere in change detection, possible asymmetries in working memory performance should be considered as the present change-detection task also involves visual working memory. To perceive a difference between two scenes, the visual information in the first scene must be registered in working memory and compared with visual information in the second scene (eg Vogel et al 2006). With this in mind, the possibility that asymmetry in visual working memory contributed to the enhanced visual processing in the left visual field should be investigated in future studies.

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Appendix

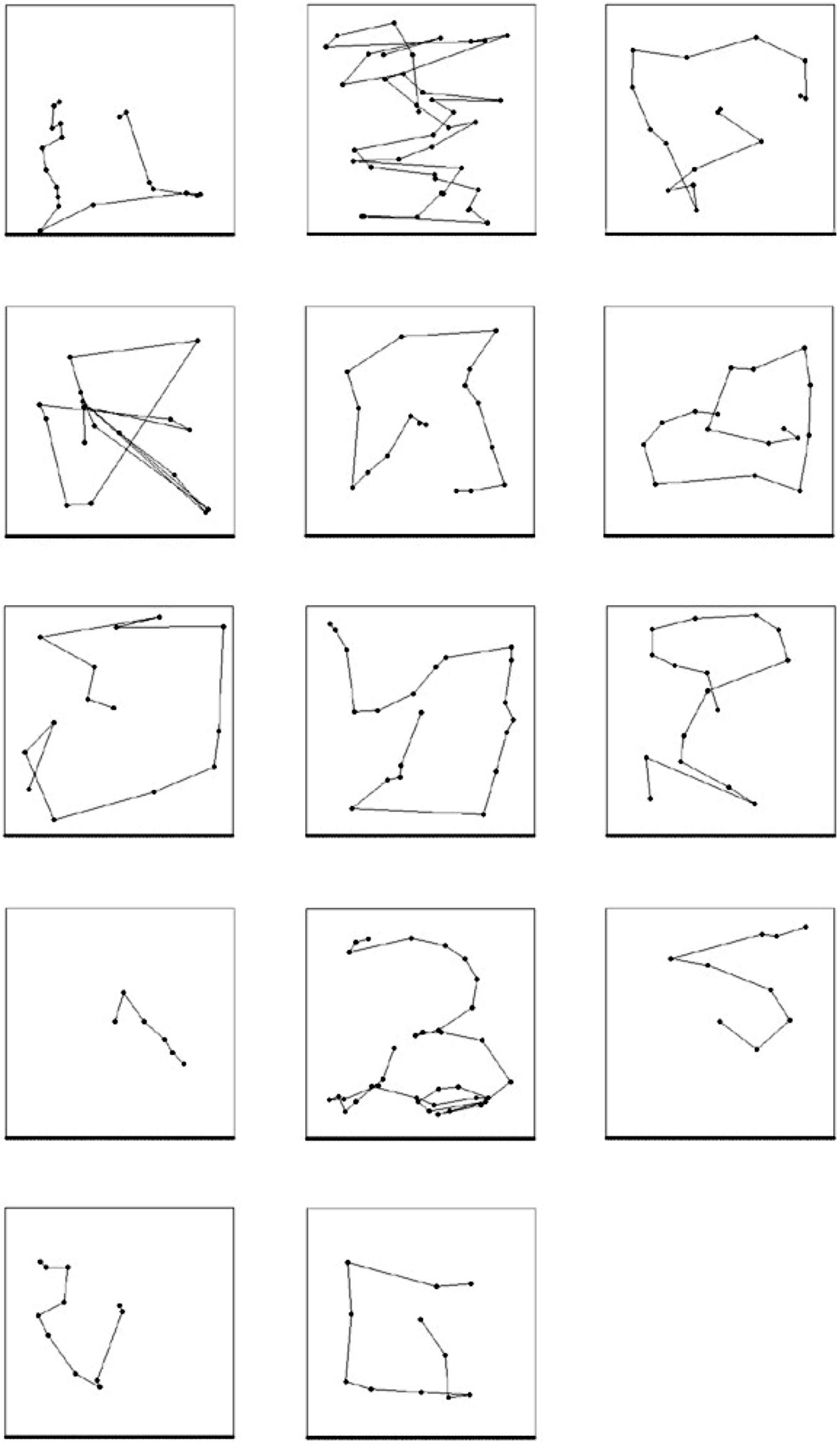

Figure A1. Sample eye-movement maps for each participant. Dots indicate fixations.

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