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Assessing effects of fixation demands on perception of lateralized words: A visual window technique for studying hemispheric asymmetry

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Abstract

A major concern when using lateralized words to study hemispheric asymmetry is that the retinal eccentricity of targets is matched across visual hemifields. The standard technique is to fixate a point fixed at the centre of the visual field. However, the demands of this fixation task are substantial and so may confound performance with lateralized targets. To investigate this possibility, words were presented unilaterally in each visual hemifield and retinal eccentricity was controlled using (a) a fixed central point or (b) a window technique that permitted small shifts in fixation while maintaining accurate retinal eccentricity by using automatic adjustments to target location. Fixation errors and time to fixate indicated that the demands of the standard technique were considerable and far greater than those of the window technique. Nevertheless, both techniques produced the same pattern of visual field effects, indicating that the demands of fixating a fixed central point do not confound performance with lateralized words. However, the window technique was more efficient and easier for participants to use and so offers a new improved methodology for studying hemispheric asymmetry.

Keywords: Hemispheric asymmetry; Word perception; Fixation; Attention

1. Introduction

Nerve fibres carrying information about stimuli falling in the left visual hemifield (LVF) project to the right lateral geniculate nucleus (LGN) and then to the visual cortex of the right cerebral hemisphere whereas fibres carrying information about stimuli falling in the right visual hemifield (RVF) project to the left LGN and then to the visual cortex of the left cerebral hemisphere. Thus, with appropriate experimental control, stimuli can be presented to whichever cerebral hemisphere is chosen by the experimenter to help reveal hemispheric asymmetries in processing.[1]

However, inferences about hemispheric processing are likely to be contaminated if stimuli are presented at different retinal eccentricities in each hemifield, and even small shifts in fixation away from the centre of the visual field can produce contamination (see Jordan, Patching, & Milner, 1998, 2000, for reviews). Assessments of the physiology of the human visual system (e.g., Green, 1970; Jones & Higgins, 1947; Polyak, 1941; Riggs, 1965; Weymouth, Hines, Acres, Raaf, & Wheeler, 1928) indicate that the visual acuity available when fixating a central fixation point drops to 30% of this level at 2° horizontal eccentricity (a typical eccentricity for lateralized targets in studies of hemispheric asymmetry). However, a rightward shift in fixation of just 20 min from the central fixation point can increase this level of acuity to 45% for RVF targets and, concomitantly, reduce it to 15% for LVF targets. Consequently, although non-central fixations may land to one side of a central fixation point by just a few minutes of arc, the difference produced in the relative visibility of LVF and RVF targets may produce a performance advantage for one hemifield because of asymmetries in retinal acuity rather than asymmetries in hemispheric processing (e.g., Jordan et al., 1998, 2000; Jordan, Patching, & Thomas, 2003a, 2003b; Patching & Jordan, 1998).

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[1] When we refer to stimuli presented to one hemisphere, we are not assuming that only this hemisphere has access to this information, simply that the contralateral hemisphere receives the information before the ipsilateral hemisphere.

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1.1. Using a fixed central fixation point in studies of hemispheric asymmetry

The importance of ensuring matched retinal eccentricity in divided visual field studies of hemispheric asymmetry is widely acknowledged and various methods have been tried (see Jordan et al., 1998, 2003a, 2003b, for reviews). However, by far the most popular method is to present a fixation stimulus (usually a small dot or cross) at a fixed, predetermined location in the centre of the visual field, midway between the locations of LVF and RVF targets, and to simply instruct participants to maintain their fixation at this fixed central point before (and during) the presentation of each target (see Jordan et al., 1998, 2003a, 2003b, for reviews). Unfortunately, instructions alone fail to ensure accurate fixation (e.g., Findlay & Kapoula, 1992; Jones & Santi, 1978; Jordan et al., 1998, 2003a, 2003b; Patching & Jordan, 1998; Sugishita, Hamilton, Sakuma, & Hemmi, 1994; Terrace, 1959). For example, Jordan et al. (1998) (see also Jordan et al., 2003a, 2003b) monitored fixation of a fixed central point during lateralized word displays using an eye tracker. Despite emphasized instructions to fixate the fixed central point, and randomised presentations of targets between the left and right hemifields, central fixations occurred on only 23% of trials and the majority (64%) of non-central fixations fell to the right of the central point.[2] To overcome these variations in fixation accuracy, researchers ensure fixation of a fixed central point by using an eye tracker. For example, Jordan et al. (1998) (see also Jordan & Patching, 2003a, 2003b, 2004; Patching & Jordan, 1998) used the standard technique of a fixed central fixation point but controlled the onset of lateralized word targets by using an eye tracker interfaced with a computer. This arrangement allowed presentation of lateralized targets only when the eye tracker indicated central fixation and so ensured accurate target retinal eccentricity on each trial.

1.2. Does requiring accurate fixation of a fixed central point place confounding demands on participants?

The perceptual and cognitive simplicity of using a fixed central fixation point make it well-suited to studying the processing of lateralized words and, when coupled with an eye tracker to ensure accurate fixation, the technique provides an effective method for controlling retinal eccentricity in studies of hemispheric asymmetry. However, whilst the importance of accurate central fixation is clear, it remains to be seen whether the demands of accurately fixating a fixed central point actually confound the processing of lateralized words.

According to Kowler (1990), fixations of small isolated stationary targets, like a fixed central point, are extremely stable over several seconds when the head is firmly supported, suggesting that the demands of maintaining central fixation under these conditions are small. Indeed, Ratliff and Riggs (1950) (see also Steinman, 1977; Steinman, Haddad, Skavenski, &Wyman, 1973) found that the total movement of the eyes over a period of several seconds is usually less than 10 min of arc, occurring equally often to the left and right of fixation, and Steinman et al. (1973) observed that maintaining stable fixation of a fixed central point is simple to do and requires no special training.

However, these findings were made using paradigms in which only fixation stimuli were presented. In contrast, accurately fixating a fixed central point in studies of hemispheric asymmetry where the primary task is to identify targets presented peripherally in the visual field is a difficult task for participants (Jones & Santi, 1978; Jordan et al., 1998, 2003a, 2003b; Terrace, 1959), even participants who are highly motivated and experienced (e.g., Findlay & Kapoula, 1992). Indeed, without the control of an eye tracker, participants find that the suppression of eye movements required to fixate a fixed central point in this type of experiment is essentially impossible to do (e.g., Findlay & Kapoula, 1992; Jones & Santi, 1978; Jordan et al., 1998, 2003a, 2003b; Terrace, 1959).

These fixation difficulties in studies of hemispheric asymmetry are consistent with the findings of studies that have investigated the link between accurate central fixation and the suppression of eye movements towards targets in the periphery (e.g., Fischer, 1986; Mackeben & Nakayama, 1993; Reuter-Lorenz, Hughes, & Fendrich, 1991; Sheliga, Kuznetsov, & Shul'govskii, 1991; for a review, see Fischer & Breitmeyer, 1987). In particular, findings from these studies suggest that when fixating a fixed central point, rapid involuntary eye movements directed towards the location of peripheral targets can occur and are suppressed only when participants are attending the fixation point. (Indeed, the findings of Breitmeyer & Valberg, 1979, suggest that stimulation from stimuli in the periphery may actually suppress the processing of stimuli in the fovea, making the task of accurate central fixation even more difficult under conditions of lateralized target presentation.) Thus, whereas the task of accurately fixating a fixed central point appears to require little effort when it is presented in isolation, the same task may place considerable demands on participants when a fixed central point is used to ensure accurate retinal eccentricity in studies of hemispheric asymmetry. Of further concern is that the demands of accurate central fixation may actually interfere with the processing of lateralized targets. Hoshiyama and Kakigi (2001) presented visual stimuli (checkerboards) in peripheral locations and recorded the visual evoked potential (VEP) produced by these stimuli under a variety of fixation conditions. In the control fixation condition, participants were asked merely to fixate on the centre of the visual field. However, when the demands of the fixation task were increased by requiring participants to "gaze and mentally concentrate" on a fixed central fixation point, VEP to foveal stimulation was enhanced and VEP to peripheral stimulation was suppressed, relative to a control condition in which these demands were not made.

[2] It is important to emphasize that presenting targets randomly in the left and right hemifields does not prevent systematic biases in fixation location. Consequently, although the vast majority of experiments using lateralized word displays to investigate hemispheric asymmetry have used a fixed central point, with only instructions to fixate, and targets presented randomly in the left and right hemifields, it is not sufficient to assume that non-central fixations add merely random error variance to the data. Indeed, it should also be pointed out that, in view of the non-linear distribution of information throughout a word, even random variations in fixation location may inspire systematic artefactual differences in performance between the two hemifields (see Jordan et al., 1998, 2000, 2003a, 2003b).

It would be of considerable concern for studies of hemispheric asymmetry if the scientific benefits provided by accurate central fixation were compromised by demands that confounded the processing of lateralized targets. Indeed, many researchers have argued for a role for attention in processing lateralized words (e.g., Bryden, 1980; Kinsbourne, 1970; Larson & Brown, 1997; Mesulam, 1981) and a number of studies suggest that whereas the left hemisphere can process words when few attentional resources are allocated to the task, the right hemisphere requires more attentional resources to perform the same task (e.g., Mondor & Bryden, 1992; Nicholls & Wood, 1998; Nicholls, Wood, & Hayes, 2001). Thus, when attentional resources are assigned elsewhere, performance is disrupted more for LVF words than for RVF words, which may not be affected at all. If the demands of accurately fixating a fixed central point disrupt the normal allocation of attention for processing lateralized words, the findings produced by studies using this fixation technique may inflate RVF advantages and so produce spurious indications of hemispheric asymmetries.

Accordingly, the research reported in this article introduces a new technique for studying hemispheric asymmetry. Specifically, we used a moving virtual window in which inaccuracies in participants' fixation of up to 0.5° either side of a central fixation point (the typical range of fixation inaccuracies in experiments using lateralized displays; e.g., Jordan et al., 1998) were accommodated by precise lateral adjustments in the location at which the word target was presented on that trial. In this way, inaccurate fixations did not alter the actual, matched retinal eccentricity at which words were presented in each visual hemifield but the demands placed on participants by the standard technique of accurately fixating a fixed central point were removed. If the demands of the standard technique affect the processing of lateralized words, different patterns of performance should be produced when these demands are removed by the window technique. In particular, if the demands of accurately fixating a fixed central point disrupt the role of attention in processing words, overall performance for lateralized words should be higher, and the typical RVF advantage should be lower, when using the window technique. On the other hand, if the demands of the standard technique are not disruptive, standard and window techniques should produce similar patterns of word performance.

2. Experiment

2.1. Methods

2.1.1. Participants

Twelve paid undergraduate students each participated in two sessions, one on each of 2 different days. All participants were native speakers of English and were classified as right-handed by self-report and a revised version of the 12 item Annett Handedness inventory (Annett, 1967). All participants reported normal or corrected-to-normal vision, and were screened using a Bailey–Lovie eye chart (Bailey & Lovie, 1976) to ensure normal visual acuity.

2.1.2. Stimuli

Testing was achieved using the Reicher–Wheeler two-alternative forced choice task (see Jordan et al., 2000). One hundred and twenty-eight matched pairs of four-letter words were selected as experimental stimuli, with a mean frequency of written occurrence of 210 per million (Carroll, Davies, & Richman, 1971). The members of each word pair differed by just one letter (e.g., word, work) and these differences occurred equally often at each of the four-letter positions. Half the participants received one member of each word pair as a target and half the other member. The pair-mate for each target was used as the alternative response in the Reicher–Wheeler task. An additional 48 matched pairs of four-letter words provided practice stimuli at the beginning of each session. A single but clearly visible pixel was used as a central fixation point on each trial. To provide feedback on fixation accuracy (Steinman, 1977) the fixation point pulsated slowly until accurate fixation occurred.

2.1.3. Visual conditions

Viewed from a distance of 57 cm, the visible area of the display screen measured 29° vertically and 23° horizontally. Words were presented in black 14-point Times New Roman font on a white background and subtended a horizontal visual angle of 1°. Background screen luminance was 46 cd/m^2 and stimulus luminance was 0.15 cd/m^2.

2.1.4. Fixed and window conditions

The eye-tracking equipment was calibrated for each participant at the start of each session (Beauvillain & Beauvillain, 1995; Patching & Jordan, 1998). Each trial in the fixed and window conditions began with the presentation of the pulsating fixation point at the centre of the screen. Participants were instructed to accurately fixate the fixation point on each trial and these same instructions were given in the fixed and window conditions. Fixation locations were monitored continuously throughout each trial.

In the fixed condition, participants were required to accurately fixate the location of the central fixation point when a target was shown. To ensure this, the fixation point pulsated until accurate fixation occurred continuously for 1 s.[3] The fixation point then stopped pulsating which indicated to participants that they could initiate a target display. If fixation shifted from the central fixation point at any time prior to target presentation, target presentation was withheld and the pulsating central fixation point was shown again until accurate fixation occurred continuously for 1 s. In the window condition, the fixation window was always centred on the location of the central fixation point and participants were allowed to fixate up to 0.5° left or right of this location when a target was shown. In this condition, the fixation point pulsated until fixation occurred within the fixation window continuously for 1 s. The fixation point then stopped pulsating, which indicated to participants that they could initiate a target

[3] We found that 1 s ensured a steady fixation rather than a 'fleeting glance' (see, e.g., Hellige & Sergent, 1986) and was a reasonable time to ask participants to fixate centrally.

display. If fixation shifted outside the fixation window at any time prior to target presentation, target presentation was withheld, and the pulsating central fixation point was shown again until fixation within the fixation window occurred continuously for 1 s. No change in fixation location occurred during any target display in either fixation condition.

In the fixed condition, each word was presented so that its inner edge was 2° from the location of the fixed fixation point, in the LVF or RVF. In the window condition, each word was presented so that its inner edge was 2° from the point of fixation, in the LVF or RVF, regardless of where in the fixation window participants were fixating. When fixation occurred within the window, the fixation point shifted to the point of fixation and the location at which the lateralized word target was presented on that trial was adjusted accordingly. For example, if fixation in the window was 15 min to the right of the location of the central fixation point, the fixation point shifted to this location and, if a target was presented during this fixation, the location at which the target was presented (in the LVF or RVF) was also moved 15 min to the right to maintain a constant 2° retinal eccentricity in both hemifields.

2.1.5. Design

Participants took part in both fixation conditions, one in each of two different sessions. Session order was counterbalanced across participants. In each session, each word was presented in each visual hemifield and all words were presented in pseudo-random cycles of 16 items, counterbalanced across visual hemifield and critical letter position. Half the participants used the index finger of their right (preferred) hand to respond while the remainder used the index finger of their left (non-preferred) hand.

2.1.6. Apparatus

The position of each eye was monitored using a Scalar IRIS light reflecting eye-tracking system (Skalar Medical BV, Delft, The Netherlands). The eye tracker was clamped to the head of each participant and the head of each participant was clamped in a head brace throughout the experiment to avoid head movements. The output of the eye tracker was recorded through the ADC input of a Cambridge Research Systems (Rochester, Kent, UK) visual stimulus generator (VSG2/5) card, which also controlled each visual display. Visual signals were presented on a Sony Trinitron F500R visual display monitor and participants entered their responses via two keys interfaced with the computer.

2.1.7. Procedure

At the start of each session, each participant was familiarized with the 26 letters of the character set used in the experiment and instructed to accurately fixate the fixation point on each trial. When participants initiated a trial in either fixation condition, the fixation point was replaced immediately by the following display sequence: target; 500 ms blank; two forced-choice alternatives. To present the forced-choice alternatives, four dashes were shown in the centre of the screen, corresponding to the four letter-positions in a four-letter word. At one of these dashes, two letters were shown, one above the dash and one below (randomly determined) and participants decided which letter had been shown in the target at the position indicated by the dash. To make their choice, participants pressed a response key to select either the upper or lower alternative. Target exposure duration was 50 ms in both fixation conditions.

3. Results

In the fixed condition, participants fixated the location of the central fixation point during target presentation on 100% of trials and, in the window condition, participants fixated within the fixation window during target presentation on 100% of trials. However, in the window condition, participants actually fixated the location of the central fixation point during target presentation on only 52% of trials; 30% of fixations fell to the left and 18% to the right, up to 0.5° away from the location of the central point. Regardless of where participants were actually fixating within the fixation window, target stimuli were always presented with the same retinal eccentricity in the LVF and RVF.[4]

To assess the difficulty of fixating in each fixation condition, the time taken and the number of fixation errors made before accurate fixation occurred in the fixed and window conditions were measured on each trial from the onset of the fixation point to the onset of the (final) fixation that enabled the presentation of the target. Each measure was submitted to an analysis of variance (ANOVA) with one between-subjects factor (response hand) and one within-subject factor (fixation condition; fixed, window). Analysis of time taken revealed a main effect of fixation condition, $F(1,10) = 16.99$, $p < .005$, and no other main effect or interaction. Participants took almost three times as long to fixate accurately in the fixed condition than in the window condition (for each trial, $M = 3.94$ and 1.32 s, respectively). For analysis of fixation errors, fixation errors in the fixed condition were fixations that fell outside the location of the central fixation point and, in the window condition, fixations that fell outside the fixation widow. The analysis revealed a main effect of fixation condition, $F(1,10) = 14.68$, $p < .005$, and no other main effect or interaction. Participants made 14 times more fixation errors in the fixed condition than in the window condition (for each trial, $M = 14$ and 1, respectively).

Data for accuracy of target identification (see Figs. 1 and 2) were submitted to an ANOVA with one between-subjects factor (response hand) and three within-subject factors (fixation condition, fixed, window; visual hemifield, LVF or RVF; critical letter position). The analysis revealed main effects of visual hemifield, $F(1,10) = 22.68$, $p < .001$, and critical letter position, $F(3,30) = 47.96$, $p < .0001$. Stimuli were perceived more accurately in the RVF (77.5%) than in the LVF (71.0%). Newman–Keuls tests showed that letters were identified more accurately in exterior positions (1 and 4) than in interior posi-

[4] Rightward and leftward biases in fixation location have both been reported when central fixation is required (see Jordan et al., 1998) and this variability underscores the problems of this confounding variable when accurate fixation is not ensured.

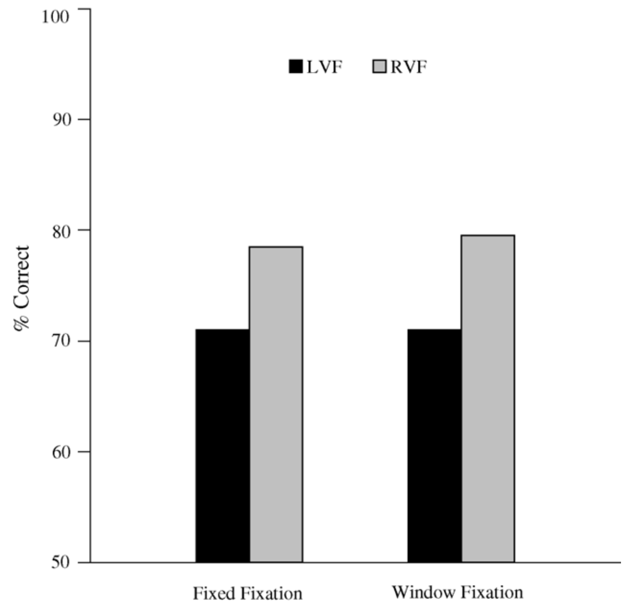

Fig. 1. Mean percentage of correct responses to words in the left visual field and right visual field in the fixed fixation and window fixation conditions.

tions (2 and 3; all ps < .01) and no more differences were found. The ANOVA revealed no other main effects or interactions. In particular, fixation condition did not interact with any factor.

4. General discussion

The primary purpose of this research was to determine whether the demands of accurately fixating a fixed central point confounded the processing of lateralized targets in studies of hemispheric asymmetry. The time taken to fixate accurately and the number of fixation errors both indicate that accurately fixating a fixed central point was a very demanding task but that fixating in the window condition was quite effortless. Indeed, while an average of 14 fixation errors were made before accurate fixation of the fixed central point occurred, the fixation window produced an average of just a single fixation error on each trial. However, despite the difference in task demands, both fixation conditions produced essentially identical patterns of target performance. Specifically, both fixation conditions produced the same overall levels of report accuracy, the same advantage for RVF words, and the same patterns of accuracy across serial positions. This last point is particularly informative because serial-position performance provides a fine-grained analysis of processing in each fixation condition, and indicates that the "U-shaped" pattern of orthographic analysis often reported for lateralized words (for reviews, see Jordan et al., 2000, 2003a, 2003b) not only occurred in our study but remained unaffected by changes in fixation demands (cf. arguments by Nazir, 2003).

These findings provide a powerful indication that using a fixed central point to ensure accurate retinal eccentricity in studies of hemispheric asymmetry does not confound processing of lateralized words. Indeed, whereas previous research indicates that considerable demands are placed on participants required to fixate a fixed central point in studies of hemispheric asymmetry and that processing of lateralized stimuli may suffer when the demands of processing a foveal stimulus increases, our findings indicate that the demands of fixating a small, fixed central point, although considerable, do not disrupt the absolute or relative perceptibility of words in either visual hemifield. Thus, while aspects of hemispheric asymmetries that are affected by task demands (such as the allocation of attentional resources) may be a component of performance differences between the two hemifields, accurately fixating a fixed central point appears to control retinal eccentricity without creating task demands that either suppress or contaminate the effects of hemispheric asymmetry on target word performance (cf. arguments by Nazir, 2003).

It is clear from the literature that researchers using lateralized targets to study hemispheric processing are widely aware of the importance of matching retinal eccentricity in the LVF and RVF by ensuring central fixation throughout each target display (why else would researchers using lateralized targets instruct their par-

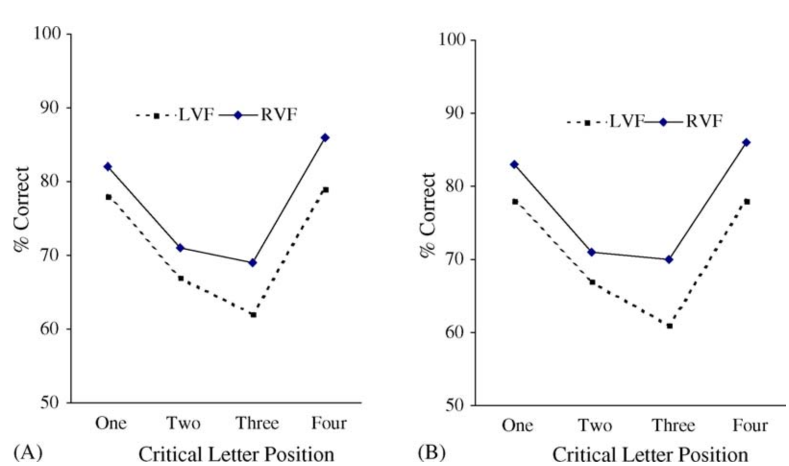

Fig. 2. Mean percentage of letters correctly reported (% correct) in each critical letter position for words in the left visual field and right visual field in (A) the fixed fixation condition and (B) the window fixation condition.

ticipants to fixate the central fixation point before and throughout each target display?). In addition, because instructions alone are inadequate, studies in which an eye-tracking device is used to control fixation location do so to ensure that the laudable intention of ensuring central fixation is realized. Before conducting this study, a major concern was that ensuring accurate fixation of a fixed central point created problems that impacted on the very validity of the practice of using lateralized displays to study hemispheric asymmetries. The indication now is that ensuring accurate fixation of a fixed central point in studies of lateralized word perception provides important increases in presentation accuracy that are not offset by confounds in target processing.

4.1. A new approach to controlling fixation location in laterality research

However, while the validity of using a fixed central point to ensure fixation accuracy in displays of lateralized targets gains support from our findings, the window technique offers a number of benefits that may be attractive to researchers. It is apparent that many participants in experiments using lateralized displays find accurately fixating a fixed central point very difficult, even impossible, to do. Indeed, in our own laboratory, participants with normal visual abilities occasionally present themselves for preliminary testing and are unable to fixate accurately on a fixed central point in experiments using lateralized displays, and are thus unsuited to taking part in experiments where central fixation is essential. This limitation presents additional, hidden problems for studies in which an eye tracker is not used to assess and control fixation accuracy. However, it also means that a proportion of the population are unsuited to experiments using lateralized displays, which places unwelcome restrictions on the application of this type of research, and its findings, to investigating hemispheric functioning. Moreover, even when participants can fixate accurately and take part in studies using lateralized displays, eye movements (involuntary and voluntary) away from the point of central fixation can also disrupt experiments. Thus, when a fixed point is used for central fixation, fixation control can operate only within the limits determined by participants' abilities to control their own fixations. Both these problems are reduced substantially by the window technique. In particular, provided only that participants can maintain fixation within a fixation window, presentation of lateralized targets can take place with the precise control over retinal eccentricity required for meaningful research in this area. Indeed, on a more pragmatic note, participants in our study took just one-third of the time to fixate accurately when using the window technique (relative to the standard technique of fixating a fixed central point). Thus, in an experiment using hundreds of trials, saving even a few seconds per trial can reduce substantially the duration of the experiment, and the tedium experienced by participants.

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