THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 1998, *51A* (2), 371–391

Central Fixations are Inadequately Controlled by Instructions Alone: Implications for Studying Cerebral Asymmetry

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A fundamental concern when using visual presentations to study cerebral asymmetry is to ensure that stimuli are presented with the same degree of retinal eccentricity from a central fixation point in either visual field. However, a widely used procedure intended to control fixation location merely *instructs* participants to fixate appropriately without any other means of ensuring that central fixations actually occur. We assessed the validity of assuming that instructions alone ensure central fixation by using the traditional RVF advantage for words and either (a) only instructions to fixate centrally, or (b) an eye-tracking device that ensured central fixation on every trial. Experiments 1 and 2 found that when only instructions were given, the vast majority of fixations were not central, and more occurred to the right of centre than to the left. Moreover, the prevalence of non-central fixations was otherwise disguised by the finding that both fixation procedures produced similar RVF advantages in overt performance. The impact of typical non-central fixations on performance was revealed by systematically manipulating fixation location in Experiment 3, where deviations in fixation of only 0.25° from centre had a reliable impact on visual field effects. Implications of these findings for studies of cerebral asymmetry are discussed.

Anatomically, the arrangement of the human visual system is such that nerve fibres carrying information about stimuli falling in the left visual hemifield (LVF) project to the right lateral geniculate nucleus 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 lateral geniculate nucleus and then to the visual cortex of the left cerebral hemisphere. Thus, provided a person's point of fixation can be accurately determined, stimuli can be projected to whichever visual hemifield (and, therefore, directly to whichever cerebral hemisphere) is chosen by the experimenter. This makes such tasks ideal for studying the neurological distribution of function across hemispheres, the nature of the transfer of complex information between hemispheres, and, by

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This research was funded in part by a University of St. Andrews Research Award. We are grateful to Jon Driver, Mike Nicholls, and an anonymous reviewer for their thoughtful comments.

suitable experimental manipulations, the temporal dynamics of interhemispheric processing in the normal intact brain. Indeed, investigations of visual field asymmetry have remained prominent in the study of hemispheric specialization since Mishkin and Forgays (1952) tachistoscopically exposed words to each visual hemifield and found an advantage for words presented in the RVF.

However, before accurate inferences can be made about the processing of stimuli by the two cerebral hemispheres, researchers must ensure that participants are fixating centrally so that stimuli presented to the left or right hemiretina of each eye have the same degree of retinal eccentricity. Without this control, stimuli may be projected to the wrong cerebral hemisphere or to both cerebral hemispheres, or they may enjoy a perceptual advantage over stimuli presented in the other visual hemifield simply because of differences in retinal acuity. The need to control participants' fixation location in lateralized displays has been recognized for a number of years. For example, Terrace (1959) used electomyographic recordings to monitor eye movements and found that participants presented with lateralized displays made anticipatory eye movements to the right of a central fixation point. In another study, Jones and Santi (1978) monitored fixations and eye movements using electrodes placed at the external canthus of each eye. When participants' central fixation was ensured, report accuracy was the same for each visual hemifield. However, when this control over fixation location was relaxed, accuracy was greater for stimuli presented in the RVF, which, Jones and Santi concluded, was due to anticipatory eye movements made towards the RVF. Thus, unless central fixation is ensured when lateralized stimuli are presented, it is impossible to be certain that differences in performance across visual hemifields reflect underlying asymmetry in hemispheric processing and not artefactual influences of non-central fixation.

Methods of Assessing Fixation Location

Although there is general agreement over the importance of central fixation (e.g. Bradshaw & Nettleton, 1983; Hellige & Sergent, 1986; Maddess, Rosenblood, & Goldwater, 1973; McKeever & Huling, 1971), much less agreement exists over the best way to ensure this. In particular, even though a range of techniques for ensuring central fixation have been employed over the years, it has recently become common merely to instruct paricipants to fixate centrally, without actually monitoring fixation location (e.g. Chiarello, Nuding, & Pollock, 1988; Chiarello, Senehi, & Soulier, 1986; Eng & Hellige, 1994; Eviatar & Zaidel, 1991; Faust, Kravetz, & Babkoff, 1993; Hellige, Bloch, & Taylor, 1988; Hellige & Michimata, 1989; Jackman, 1985; Kitterle, Christman, & Conesa, 1993; Koenig, Wetzel, & Caramazza, 1992; Lukatela, Carello, Savic, & Turvey, 1986; Moscovitch & Radzins, 1987; Tramer, Butler, & Mewhort, 1985). However, despite the widespread use of instructions alone, little is known about the effectiveness of this procedure for ensuring that central fixations actually occur. The purpose of the present article, therefore, is to examine the validity of the "instructions only" procedure for studies of hemispheric asymmetry. However, let us first place this procedure in the context of other attempts to control fixation location.

Indirect Methods

One indirect method of attempting to ensure central fixation is to ask participants to report a fixation stimulus (e.g. a small digit) presented at the central fixation point prior to (or immediately after) reporting a target stimulus presented in the left or right visual hemifield (e.g. Alter, Rein & Toro, 1989; Banich & Belger, 1990; Boles, 1983, 1985; Hellige, Taylor & Eng, 1989; Luh & Levy, 1995; McKeever & Huling, 1971; Tapley & Bryden, 1983; Wagner & Harris, 1994). The logic of this approach is that fixation stimuli can be reported only when central fixation is taking place. However, the use of a seconday task to ensure central fixation has two major disadvantages, either of which may contaminate the pattern of effects obtained with lateralized stimuli. First, correct identification of a fixation stimulus does not ensure central fixation unless the physical characteristics of this stimulus are such that *any* shift away from central fixation would prevent recognition. Attempts can be made to ensure that the stimuli used to control fixation cannot be recognized unless fixated (e.g. Boles, 1983, 1985). For example, it is possible to vary the exposure duration, luminance, or size of any centrally presented stimuli independently of peripherally presented stimuli in an attempt to ensure that participants can report the fixation stimulus only when it is fixated. However, although the use of fixation stimuli may encourage central fixation, it is far from certain that this technique actually ensures central fixation, even on trials when a fixation stimulus has been accurately reported. In particular, because of individual differences in visual acuity and because participants may experience practice effects as they work through an experiment, the appropriate physical parameters for ensuring central fixation are likely to vary. Consequently, a fixation stimulus that may be difficult for some participants to recognize whithout central fixation may be recognized by others even when fixating to one side of centre. Additionally, a fixation stimulus that may be difficult to recognize at the beginning of an experiment may become easier to resolve as the experiment progresses (e.g. through increased familiarity with the physical characteristics of the stimuli; see e.g. Wolford, Marchak, & Hughes, 1988) and this may also permit accurate identification when fixating to one side of the required central location.[1]

The second disadvantage is that reporting a fixation stimulus as well as reporting a peripheral target stimulus may interfere with the processing of the target stimulus and almost certainly changes the information-processing demands of the task. In particular, participants must perform two tasks on each trial, and this may have a substantial effect

[1] Problems of individual differences and practice effects may be reduced if the physical parameters of fixation stimuli are determined individually for each participant before the experiment starts and are altered to accommodate subjective changes in perceptibility throughout the experiment. Thus, for example, encouragement to fixate centrally may be greater if the physical parameters of fixation stimuli are adjusted to maintain the perceptibility of these stimuli at threshold. However, even if one assumes that report of the fixation stimulus accurately reflects the perceptibility of this stimulus when fixated (and not, for example, an accurate guess when fixation is not central), any necessary adjustments due to a shift in performance with fixation stimuli must necessarily be retrospective, based on accuracy of report on previous trials. Consequently, even determining the physical parameters of fixation stimuli individually for each participant and accommodating subjective changes in perceptibility throughout the experiment permits a shift away from an ideal level of fixation stimulus report (where participants can recognize fixation stimuli only if they are centrally fixating) on some trials and so fails to ensure that performance with lateralized stimuli is not contaminated by shifts in fixation location.

on the pattern of performance observed with lateralized target stimuli, especially if the primary task (target stimulus recognition) and secondary task (fixation stimulus recognition) have overlapping cognitive demands. Hines (1972) was one of the first to voice such concerns, which were later reiterated by Carter and Kinsbourne (1979), who found that changes in the nature of centrally presented stimuli changed the pattern of performance produced by laterally pesented digits. Other, arguably less interfering, secondary tasks have been used, although their efficiency remains in doubt. For example, Schmuller and Goodman (1979; see also Boles, 1990) presented words bilaterally, with an arrow presented at the central fixation location that determined the order in which each pair of target stimuli should be reported. However, although a simple arrow may create relatively little interference with the cognitive processes used for processing lateralized stimuli, some residual interference is likely even if its extent and effect is difficult to determine. Moreover, our earlier arguments concerning individual differences in visual acuity and the influence of practice effects suggest that this task also provides only weak indications that participants are fixating centrally on every trial.

In a variation of the fixation stimulus procedure, Young and Ellis (1976) presented target stimuli either centrally or in the left or right visual hemifield. The rationale behind this approach was that participants who were fixating centrally should show better performance when stimuli were presented centrally rather than laterally. However, better performance with central stimuli does not necessarily indicate central fixation; for example, fixating slightly to one side of centre may still produce greater recognition accuracy for stimuli presented centrally while inspiring an artefactual increase in performance for lateralized stimuli presented on the same side as fixation.

Direct Methods

Direct methods of ensuring central fixation overcome some (but not all) of the problems associated with indirect techniques. Without doubt the most transparent method of directly assessing fixation location is to use eye-tracking equipment, and some studies have used this technique to ensure central fixation (e.g. Chiarello, Dronkers, & Hardyck, 1984; Christman, 1990; Hardyck, Chiarello, Dronkers, & Simpson, 1985; Sturm, Reul, & Willmes, 1989). For example, in the study of Hardyck et al. (1985), participants were required to fixate centrally at the start of each experimental session and the co-ordinates of their eye position were determined and recorded. The presentation of each lateralized target was then withheld until the fixation co-ordinates returned from the eye-tracking device were within 0.125° of visual angle of the central fixation co-ordinates. Thus, when used correctly, eye-tracking equipment offers a way to overcome problems associated with indirect techniques and provides precise objective control over fixation location.

However, the use of eye-tracking equipment to ensure central fixation in lateralized research is rare, perhaps due to the financial cost of these devices and the time-consuming procedures required to calibrate and exploit their accuracy. In contrast, many researchers have adopted a far more straightforward, direct method of assessing fixation location by simply watching participants' eyes (e.g. Berlucchi, Tassinari, Marzi, & Di Stefano, 1989; Ladavas, Pesce, & Leandro, 1989; Maddess et al., 1973; Mohr, Pulvermüller, & Zaidel, 1994; Nicholls & Atkinson, 1993; Schwartz, Montagner, & Kirsner, 1987; Simion, Bagnara, Bisiacchi, Roncato, & Umilta, 1980; Young, Bion, & Ellis, 1980). Simion et al. (1980), for example, monitored fixation by watching participants' eyes in a mirror, whereas Young et al. (1980) used a low-illumination video camera that received a magnified image from a half-silvered mirror placed inside the tachistoscope, with four reference lights that reflected off the cornea to facilitate monitoring. However, a major problem with attempting to ensure central fixation by watching participants eyes is that this procedure involves an observer making subjective decisions about fixation location, which could be affected by a number of unwanted influences, including the experimental hypothesis, changes in levels of vigilance (and patience!) across trials and across participants, and even inaccurate perception of fixation location. Without knowing that observers provide consistent, accurate judgements of fixation location, it is impossible to be confident that subjectively monitoring participants' eyes is an appropriate technique for lateralized research.

The Use of Instructions Alone

In view of the problems associated with other attempts to monitor fixation location, it is perhaps not surprising that the most popular procedure for controlling fixation location in divided visual-field studies of cerebral asymmetry is merely to instruct participants to fixate the required fixation location (e.g. Burgess & Skodis, 1993; Chiarello et al., 1986, 1988; Chiarello, Maxfield, Richards, & Kahan, 1995; Diesch, 1995; Eng & Hellige, 1994; Eviatar & Zaidel, 1991; Faust et al., 1993; Hellige et al., 1988; Hellige & Michimata, 1989; Jackman, 1985; Kitterle et al., 1993; Koenig et al., 1992; Lukatela et al., 1986; Miossec, Kolinsky, & Morais, 1993; Moscovitch & Radzins, 1987; Richards & Chiarello, 1995; Robertson, 1995; Tramer et al., 1985). The main attraction of this approach is that it is simple and allows an uncontaminated presentation procedure that is not subject to the problems associated with the monitoring techniques described earlier. However, the efficacy of this approach is open to question.

The underlying rationale of attempting to ensure central fixation by instructions alone has three basic assumptions: (a) each participant has sufficient ocular control to achieve and maintain central fixation; (b) each participant will adhere precisely to the instructions given to them by the experimenter; (c) each participant is consistently the best judge of where they are fixating. Although there is some evidence to suggest that participants do have sufficient ocular control to maintain steady fixation (see, e.g., Kowler, 1991, for a review), the validity of the remaining assumptions underlying this technique are doubtful. First, in view of the diversity of human nature, it would be naive to assume that all participants in any experiment adhere precisely to the instructions given by the experimenter on every trial. Although this is a general concern in psychological research, its effect may be particularly devastating for studies of hemispheric asymmetry, where even a small shift in fixation location can have a large impact on performance. Second, even assuming that participants attempt to fixate centrally, subjective assessments of fixation location are prone to error. For example, Yarbus (1967) reported that participants were frequently unaware of the sizeable saccades they made when attempting to fixate. In addition, Anliker (1977) proposes that "a subject's ability to monitor his [sic] own eye movements is very limited" (p. 191). This concern is supported by the findings of Terrace

(1959) and Jones and Santi (1978) reported earlier, where, despite instructions to fixate centrally, subjects were unable to suppress anticipatory eye movements to the right of centre. More recently Batt, Underwood, and Bryden (1995) have experienced similar problems. Batt et al. required participants to identify the meaning of words presented to the LVF or RVF while fixation location was monitored using the reflection of an infrared beam from the cornea of the right eye. Despite instructions to fixate centrally, Batt et al. found that participants fixated more than 1° away from the central point of fixation on 14% (Experiment 1) and 17% (Experiment 2) of trials. (The actual number of non-central fixations is likely to have been even higher, because Batt et al. recorded fixation location only in units of 0.5° from central fixation.) Moreover (and despite Batt et al.'s suggestion that instructions alone are sufficient for conducting divided visual field studies of cerebral asymmetry), both experiments produced a fixation bias towards the LVF (cf. the RVF biases of Terrace, 1959, and of Jones & Santi, 1978) that actually achieved signficance (Experiment 1).

The argument being developed, therefore, is that although problems exist with many techniques that attempt to ensure central fixation, the widely used approach of merely instructing participants to fixate correctly has its attractions but may not provide the desired solution. Indeed, merely relying on participants' compliance with no means of objectively monitoring fixation (i.e. by using an eye-tracking device) may be even less effective than the other techniques we have discussed. Nevertheless, the asumption that instructions are sufficient to ensure central fixation is growing in popularity. In view of this growth, and in view of the critical importance of central fixation in studies of hemi-field asymmetry, we investigated the efficacy of instructions to fixate centrally over three experiments designed to replicate the often reported RVF advantage for word recognition (see e.g. Bradshaw & Nettleton, 1983, for a review).

In line with previous investigations of visual field asymmetry in which participants have merely been instructed to fixate centrally, participants in our experiments were given emphatic instructions to fixate a central fixation point when initiating each stimulus display. In addition, central fixation was further encouraged by presenting words pseudo-randomly to each visual hemifield so that participants were unable to anticipate stimulus location and so were less likely to shift their fixation from the required central location (see e.g. Hellige & Sergent, 1986). However, the actual location of each participant's fixation was objectively monitored in all our experiments using an infra-red eye-tracker calibrated to detect fixation locations in units of just 7.5 minutes of arc (see also Hardyck et al., 1985).

EXPERIMENT 1

Method

Participants

Ten paid male undergraduate students from the University of St Andrews participated in the experiment. All participants reported normal (i.e not corrected-to-normal) vision, were native speakers of English, and were classified as right-handed by self-report and by administration of an improved version of the 12-item Annett Handedness inventory (Annett, 1967).

Stimuli

Testing was achieved using a two alternative forced-choice procedure, which obviates influences of post-perceptual guessing based on orthographic knowledge (e.g. Johnston, 1978; Jordan & Bevan, 1994, 1996; Reicher 1969) associated with other testing procedures (e.g. naming; see Jordan, Patching, & Milner, 1997a, 1997b) and has previously revealed strong RVF advantages for words in lateralization experiments (e.g. Jordan et al., 1997a, 1997b; Reuter-Lorenz & Baynes, 1992). To this end, 96 matched pairs of four-letter words were selected as experimental stimuli, with a mean frequency of written occurrence of 222 per million (Carroll, Davies, & Richman, 1971). The members of each word pair differed by just one *critical* letter (e.g. s*h*ow, s*n*ow), which occurred equally often at each of the four letter positions. Two groups of 96 stimuli were formed from pseudo-random selections of the word stimuli, with each group containing one member of each matched word pair. An additional 96 matched pairs of four-letter words were constructed to provide 96 practice stimuli at the beginning of each session.

Each word target was followed by a pattern mask; this procedure permitted the use of high-contrast stimuli while maintaining overall performance at a meaningful level. For each trial, a different pattern mask was constructed from pseudo-randomly arranged fragments of the letters in the character set, with the built-in constraint that no letters were formed by these fragments. Each lateralized target-mask display was preceded by a central fixation point composed of a single pixel clearly visible to each participant.

Visual Conditions

Target words were presented on a dark-gray oscilloscope screen in a white lower-case font. Background illumination of the oscilloscope screen was approximately 1 cd/ m^2, and the luminance of target stimuli and masks was approximately 25 cd/ m^2. Stimuli were presented so that the innermost edge of each word was 2.00° either to the left (LVF) or to the right (RVF) of the fixation point. A single letter *x* subtended a horizontal visual angle of approximately 0.20°. Four proportionally spaced letter *x*s subtended a horizontal visual angle of approximately 1.10°. Each mask subtended a vertical visual angle of approximately 0.50° and a horizontal visual angle that matched that of each word target.

Design

Participants took part in one half-hour session. Each word target was presented once in each visual hemifield, in a pseudo-random order that prevented participants from correctly anticipating stimulus location. Each session was divided into 3 sections (practice, A, B), with no obvious transition from one section to the next. Each of the two presentations of each word (LVF, RVF) occurred in a different section (A or B) to ensure that the same word was not seen in close succession in the left and right visual hemifields. The allocation of stimuli to Sections A and B was re-randomized for each participant. Stimuli were shown in cycles of 8 items, counterbalanced over visual hemifield and critical letter position.

Apparatus

The position of each eye was monitored using an infra-red ACS Applied Research Developments EM 130 eye monitor, which operates by emitting low levels of (invisible) infra-red light into each eye and detecting changes in the angle at which this light is reflected. The monitor was fixed directly onto the head of each participant and had emitter and sensor heads, which could be positioned a very short distance (10 mm) from participants' eyes. The head of each participant was clamped in a head brace throughout each experiment to prevent head movement. Pretesting showed that this combination of head clamping, eye-monitor clamping, and proximal emitters and sensors allowed accurate and consistent measurement of fixation location to within 7.5 minutes of arc. Specifically, repeatedly calibrating the tracker at the start of the study enabled us to map digital output to amount of shift in fixation from centre. Thus, we knew what digital value must be exceeded for a fixation shift of 7.5 minutes of arc from centre to be exceeded. Moreover, by fixating different locations we could reliably alter the output of the tracker by constant amounts to within our 7.5-min limits. Under these conditions, our criterion for fixation at any predetermined location was a 1000-msec period during which output from the tracker never exceeded the digital value corresponding to 7.5 minutes of arc away from that location. This could be reliably achieved, indicating that the tracker's output was stable and that fixations were accurate to within our 7.5-min limits (see also Patching & Jordan in press). Consequently, when fixations were monitored but not controlled in the actual experiment, if readings corresponding to non-central fixations occured, we could be confident that these readings (and the non-central fixations they indicated) were not due to noise. The output of the eye monitor was recorded through the ADC input of a Cambridge Research Systems D300 intelligent interface, which also controlled each visual display. Input conversion time was approximately 25 μsec.

Stimuli were plotted on a Hewlett Packard 1340A oscilloscope whose rapid decay phosphor has a spot persistence time of 10 μsec to 10%. The oscilloscope had been modified to enable precise control over the visual angle of stimuli and to provide a higher resolution display (Jordan & Martin, 1987). The experiment was conducted in a darkened booth, and participants entered their responses by way of two keys interfaced with the computer.

Calibration

The eye-tracking equipment was calibrated for each participant at the start of the session by presenting one small but clearly visible pixel at a series of unpredictable horizontal distances (up to 3°) to the left or right of a central pixel (the central fixation point). Participants were instructed to fixate each non-central pixel while the output from the eye-tracking equipment was monitored and adjusted such that a change in eye position registered an equivalent change in the value returned from the eye-tracking device. This calibration procedure has considerable empirical support and is widely used in eye-movement research (e.g. Beauvillain & Beauvillain, 1995; Briihl & Inhoff, 1995; Eden, Stein, Wood, & Wood, 1994; Inhoff, 1989; Jones & Santi, 1978; Rayner & Inhoff, 1981). Calibration continued until the numerical values returned from the eye-tracking device consistently showed the same values when participants fixated previously monitored locations. Calibration checks made throughout the experiment showed no deviation in monitor accuracy.

Procedure

At the beginning of their session, each participant was familiarized with all 26 letters of the character set used in the experiment. The eye-tracking equipment was then calibrated. Participants were informed that the eye-tracking equipment would monitor their fixations throughout the experiment. Each participant was then given instructions that strongly emphasized the importance of fixating the central fixation point when receiving the presentation of a target word.

At the start of each trial, the fixation point appeared at the centre of the screen. When participants pressed either of the two keys in front of them, the fixation point was immediately replaced by the following display sequence: target; mask; 500 msec blank. Fixation location at target onset was monitored and recorded. Target exposure duration was determined individually for each participant; masks were presented for 50 msec. Four dashes were then 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, and participants had to decide which of these two letters had been shown at the position indicated by the dash. For example, the target *show* was followed by the two alternative letters *h* and *n*, positioned above and below the second of the four dashes. Participants pressed one of the two keys with the index finger of their right (preferred) hand to select either the upper or lower alternative.

Throughout the practice and experimental sections, exposure durations were re-assessed for each participant after each cycle of 8 trials. Exposure duration was increased (by 4 msec) if the number of correct responses in a particular cycle was below 5 (62.50%), and it was decreased (by 4 msec) if the number of correct repsonses in a particular cycle was above 7 (87.50%). Within each cycle, all words were shown for the same exposure duration; when adjustments to exposure duration were made at the end of a cycle, the same adjustment was made for all critical letter positions in each visual hemifield. This adjustment procedure ensured that overall performance fell in the mid-range of the performance scale and that each visual hemifield and critical letter position was represented at the same exposure duration an equal number of times. Average exposure duration for targets was 82 msec and ranged between 56 msec and 109 msec with a standard deviation of 21 msec.

Results

Two types of data were collected in this experiment—namely, accuracy of stimulus report and fixation location. The report accuracy data were submitted to an analysis of variance (ANOVA) with one between-subjects factor (stimulus group), and one within-subjects factor (visual hemifield [LVF or RVF]). A RVF advantage was observed, $F(1, 8) = 9.69$, $p < .01$; overall correct report of words presented in the RVF was 79%, whereas report of words presented in the LVF was 72%.

However, the data for fixation location (see Figure 1) showed that participants fixated centrally on only 23% of trials. Indeed, on 12% of trials participants fixated locations 0.50° or more away from the fixation point. Moreover, the total number of non-central fixations was not divided equally between the two visual hemifields—fixations fell to the right of centre on 49% of trials but to the left of centre on only 28% of trials. Of the 10 subjects, 9 fixated more to the right than to the left, $p < .0001$ by the binomial test. In additon, the distribution of fixations was significantly skewed to the right, skewness = 1.533, $Z = 27.4$, $p < .01$, indicating a greater spread of fixations towards the right periphery.

Discussion

These findings indicate that merely instructing participants to fixate centrally fails to ensure that central fixation actually takes place. If we had not monitored paticipant's fixations using an eye-tracking device, we might reasonably have inferred that the RVF advantage we observed was not contaminated by an artefactual advantage for stimuli presented to the RVF and, therefore, that the RVF advantage accurately reflected a left-hemisphere dominance for language.[2] However, the considerable RVF bias revealed

[2] The likelihood of this misinterpretation is increased by the finding that the majority of non-central fixations were within 1° left and right of the fixation point. Thus, although these deviations are substantial for psychological research, they are not spatially dramatic and so underscore our concern that less precise means of monitoring fixation location offer inadequate control (see introduction).

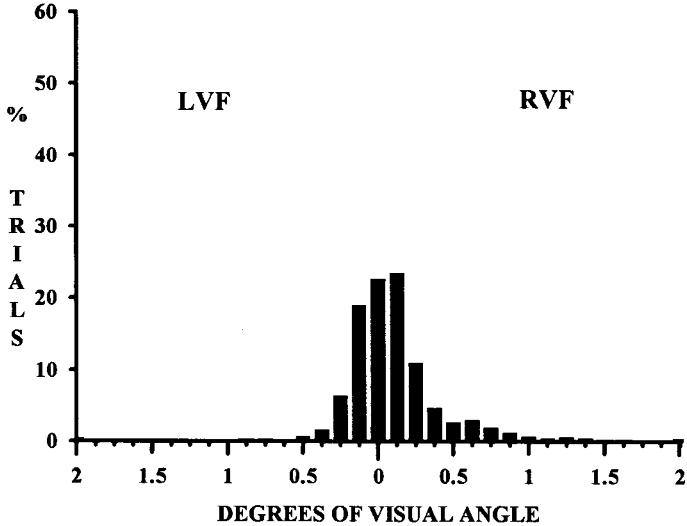

FIG. 1. Mean percentage of locations fixated (% Trials) in Experiment 1 when only emphasized instructions to fixate centrally were given.

by the fixation location data (49% vs. 28%) indicates that this conclusion should be treated with caution. Moreover, this RVF bias was obtained even though the instructions to fixate centrally in Experiment 1 are likely to have been emphasized even more than in previous studies (e.g. Chiarello et al., 1986. Chiarello et al;, 1988; Eng & Hellige, 1994; Eviatar & Zaidel, 1991; Faust et al., 1993; Hellige et al., 1988; Hellige & Michimata, 1989, Jackman, 1985; Kitterle et al., 1993; Koenig et al., 1992; Lukatela et al., 1986; Moscovitch & Radzins, 1987; Tramer et al., 1985) because participants were fitted with eye-tracking equipment and informed that their fixation locations would be monitored. Consequently, the finding that participants fixated right of central on 49% of trials may actually be a conservative measure of the lack of control provided by instructions alone.

However, the extent to which non-central fixations generated the RVF advantage in Experiment 1 remained unknown. Therefore, Experiment 2 repeated Experiment 1 (where only instructions to fixate centrally were used) and included an additional condition in which output from the eye-tracking device was used to withhold stimulus presentation until participants fixated centrally on each trial. If overt performance with lateralized stimuli in Experiment 1 was unaffected by non-central fixation locations, a similar pattern of overt performance should be observed in Experiment 2 irrespective of whether or not central fixations were enforced by the eye-tracker. Participants who had not taken part in Experiment 1 took part in Experiment 2. This provided the opportunity to see if the visual field bias in fixation location obtained in Experiment 1 when only instructions to fixate centrally were used could be obtained with different participants. This was important since the pattern of previous findings suggests that fixation biases, when they occur, can vary across different studies and, therefore, across different participants (cf. the RVF biases reported by Terrace, 1959, and Jones & Santi, 1978, and the LVF bias reported by Batt et al., 1995).

EXPERIMENT 2

Method

Participants

Sixteen paid participants from the same population as Experiment 1 took part in Experiment 2.

Design

Participants took part in two half-hour sessions. Participants had their eye fixations monitored in both sessions. However, in one session (controlled), the stimulus display could be initiated only when participants fixated the required central fixation location, whereas in the other session (uncontrolled), participants could initiate stimulus displays independently of fixation location (as in Experiment 1). The order of controlled uncontrolled sessions was counterbalanced across participants and stimulus group.

Calibration

The eye-tracking equipment was first calibrated in the same way as in Experiment 1. This calibration was then checked using two small but clearly visible pixels, one presented at the central fixation point and one presented two degrees to the left or right. Participants were required to move the eccentric pixel, using the two response keys to move it left or right, until it precisely overlay the location of the central pixel, and then to fixate this single point for one second. This procedure added further assurance that participants were fixating the central fixation point when calibration took place.

To ensure that stimulus presentation in the controlled condition occurred only when participants were fixating centrally, the values returned from the eye tracker were tested at 1-msec intervals to ensure they fell within the pre-specified range (within 7.5 minutes of the fixation point) continuously for at least 1 sec immediately before each stimulus was presented. When this fixation criterion was satisfied, pressing either of the response keys initiated stimulus presentation.[3] However, if at any point prior to the initation of the stimulus the value from the eye tracker fell outside the pre-specified range, stimulus presentation was inhibited until accurate fixation had again occurred continuously for at least 1 sec (see Patching & Jordan, in press, for further discussion of this procedure). Output from the eye tracker in the controlled condition indicated that non central fixations generally occurred at the start of fixation for each trial until participants ‘‘settled down’’ and were able to fixate reliably on the fixation point. (This observation fits with the participants’ reports that fixation was difficult initially on ‘‘controlled’’ trials but was eventually achievable.) All remaining aspects of Experiment 2 were the same as for Experiment 1. Average exposure duration for targets was 83 msec and ranged between 59 msec and 104 msec, with a standard deviation of 19 msec.

Results

The use of an eye tracker ensured participants fixated the central fixation point on 100% of trials in the controlled condition. However, when participants were merley instructed to fixate the central fixation point, the data for fixation location (see Figure 2) showed that

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[3] We found that 1 sec was a reasonable time to ask participants to fixate centrally and had the added advantage of ensuring maintained steady fixation rather than a ‘‘fleeting glance’’ (see, e.g., Hellige & Sergent 1986).

central fixation occurred on only 30% of trials. Furthermore, as in Experiment 1, the total number of non-central fixations was not divided equally between the two visual hemifields; fixations were made to the right of centre on 40% of trials and to the left of centre on only 30% of trials. A chi square test showed that this difference was highly significant [χ^2 (1, N = 2141) = 43.7, $p < .0001$]. However, unlike the skewness to the right observed in Experiment 1, non-central fixations in Experiment 2 were significantly skewed to the left, skewness = −1.3, $Z = -28.9$, $p < .01$, indicating a greater spread of fixations towards the left periphery.

The report accuracy data were submitted to an ANOVA with one between-subjects factor (stimulus group) and two within-subjects factors (visual hemifield [LVF or RVF] and fixation control [controlled, uncontrolled]). A strong RVF advantage was observed, $F(1, 14) = 47.95$, $p < .001$; overall accuracy of report for words presented in the RVF was 77% correct for controlled and 78% correct for uncontrolled trials, whereas overall accuracy of report for words presented in the LVF was 69% correct for controlled and 70% correct for uncontrolled trials. However, no other main effect or interaction was significant, indicating that the pattern of performance observed when only instructions were given and fixations were biased towards the RVF (uncontrolled condition) did not change when central fixations were ensured (controlled condition). A similar comparison (but now with fixation control as a between-subjects factor) between the report accuracy data obtained in Experiment 1 and in the controlled condition of Experiment 2 also revealed a strong RVF advantage, $F(1, 22) = 27.53$, $p < .001$, with no other main effect or interaction.

Discussion

Like Experiment 1, Experiment 2 found that when only instructions were given, the majority of fixations were not central (although the majority fell within 1° either side of centre), and more fixations occurred to the right than to the left of centre. However, in

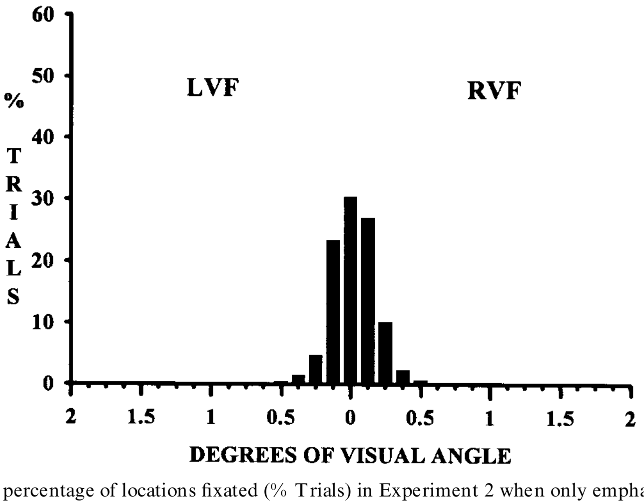

FIG. 2. Mean percentage of locations fixated (% Trials) in Experiment 2 when only emphasized instructions to fixate centrally were given.

contrast to the findings of Experiment 1, merely instructing participants to fixate centrally in Experiment 2 produced a skewed distribution of fixations towards the periphery of the LVF, indicating that although patterns of non-central fixation location were biased towards the RVF in both experiments, their precise distribution was variable. However, variations in fixation location apparently did not affect the RVF advantage. Specifically, the pattern of target report produced when only instructions were given did not differ between Experiments 1 and 2, and did not differ from that observed when central fixation was ensured in Experiment 2 using an eye-tracker. At first sight, this consistency in performance may appear to support the notion that instructions to fixate centrally provide adequate control over fixation location in studies of visual field asymmetry. However, the variability in fixation location observed in the "uncontrolled" conditions of the experiments so far provided us with too few data points for a meaningful analysis that might demonstrate an unambigious link between shifs in fixation location and hemifield performance. Consequently, to further investigate the influence of noncentral fixations on overt performance, a third experiment was conducted in which shifts in fixation location relative to target locations were systematically enforced.

EXPERIMENT 3

Method

Participants

Sixteen paid undergraduate students from the same population as Experiments 1 and 2 participated in Experiment 3.

Design

Participants took part in two 50-min sessions, one on each of two different days. Stimuli were shown in pseudo-randomly constructed cycles of 40 items, counterbalanced over visual hemifield, fixation location, and critical letter position.

Procedure

As in Experiments 1 and 2, all targets were presented so their innermost edge was 2° to either the left (LVF) or right (RVF) of the position of the central fixation point. However, on each trial, the fixation point could be presented at one of the following five fixation locations: central, 0.25° and 0.50° to the left of centre; 0.25° and 0.50° to the right of centre. Thus, for example, when fixating 0.50° to the left of centre, the innermost edge of targets presented to the LVF was just 1.50° from fixation and the innermost edge of targets presented to the RVF was 2.50° from fixation. The four non-central fixations were chosen because they formed a highly representative sample of the non-central fixations observed in Experiments 1 and 2, accounting for more than 90% of all non-central fixations produced in these experiments. In a similar manner to Experiment 2, each trial could be initiated only when the values returned from the eye tracker fell within 7.5 minutes of the desired fixation location continuously for at least 1 sec. This principle was applied to all fixation locations, thus ensuring the systematic manipulation of participants' fixation location relative to targets. The assessment of exposure duration was counterbalanced across the hemifield (relative to central fixation) in which targets were presented (LVF, RVF), fixation location, and critical letter position. Average exposure duration for targets was 69 msec and ranged between 56 msec and 88 msec, with a standard deviation of 11 msec. All remaining aspects of Experiment 3 were the same as for Experiment 2.

Results

The use of an eye tracker ensured that participants fixated the desired location on 100% of trials. The report accuracy data (see Figure 3) were submitted to an ANOVA with one between-subjects factor (stimulus group) and two within-subjects factors: visual hemifield (LVF or RVF) and fixation location (central, left 0.25°, left 0.50°, right 0.25°, and right 0.50°). A main effect of visual field was observed, $F(1, 18) = 23.60$, $p < .001$; overall accuracy of report for words presented in the RVF was 73% correct, whereas overall accuracy of report for words presented in the LVF was 67%. However, the effect of visual hemifield interacted with fixation location, $F(1, 72) = 15.15$, $p < .0001$.

Newman–Keuls tests revealed a significant RVF advantage for fixations at centre (67% vs. 73%) and progressively larger RVF advantages for fixations 0.25° to the right (66% vs. 75%) and 0.50° to the right (68% vs. 80%; all *p*s < .05). However, fixations to the left removed the RVF advantage (for 0.25° to the left, 69% vs. 70%; for 0.50° to the left, 68% vs. 66%; all *p*s > .15). Comparisons across fixation locations showed that, relative to performance with central fixations, 0.25° and 0.50° shifts in fixation location to the left or right had no effect on performance with LVF stimuli. However, performance with RVF stimuli was impaired by 0.50° shifts to the left and improved by 0.50° shifts to the right (*p*s < .05).

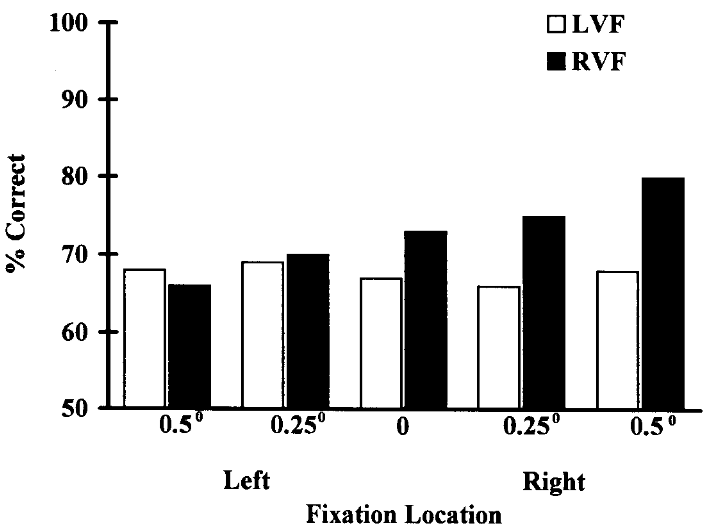

FIG. 3. Mean percentage of letters correctly identified (% Correct) in each visual field (LVF or RVF) in Experiment 3 when fixations were 0.5° to the left of centre, 0.25° to the left of centre, central (0), 0.25° to the right of centre, and 0.5° to the right of centre.

Discussion

These findings indicate that non-central fixations of the magnitude observed in Experiments 1 and 2 when only instructions to fixate centrally were given are sufficient to change the size and direction of visual field asymmetries. Indeed, even a deviation of just 0.25° to the left of fixation was sufficient to obliterate the RVF advantage observed when central fixation was actually occcurring, indicating the sensitivity of performance with lateralized stimuli to even relatively small shifts in fixation from the desired central location. However, the effect of fixation location on the RVF advantage appears to have been determined by the susceptibility of processes underlying recognition of RVF stimuli to shifts in fixation location and the absence of similar susceptibility for LVF stimuli. We shall return to this difference between effects of fixation location on performance with LVF and RVF stimuli in the General Discussion.

GENERAL DISCUSSION

The major point to emerge from the findings of these experiments is that instructions alone are insufficient to ensure central fixation on even the majority of trials in studies using lateralized displays. Indeed, the findings that non-central fixations did not occur with equal frequency in each visual hemifield and showed considerable variability across experiments indicate that instructions alone provide very little control over fixation location. In view of these problems, and in view of the problems associated with other attempts to ensure central fixation discussed in the introduction section, there seems little doubt that researchers using lateralized displays who wish to ensure that central fixation is taking place on every trial must monitor fixation locations using an eye-tracking device.

However, it is clear from the findings of Experiments 1 and 2 alone that, despite the lack of central fixations observed when instructions alone were given, the size of the RVF advantage observed under these conditions did not differ from that observed when central fixations were ensured. This similarity could be interpreted as undermining the argument that instructions alone are inadequate for studies of hemispheric asymmetry. However, this interpretation would be naïve, especially in light of the findings of Experiment 3, where small shifts in fixation location produced substantial effects on overt performance. A major concern is that the retinal eccentricity produced by even small shifts in fixation away from centre is likely to contaminate target performance. In particular, the anatomical arrangement of the retina and visual system suggests that there is an overlap at the midline of at least 1°, where information falling on the retina will pass to both hemispheres (Bunt & Minckler, 1977; Bunt, Minckler, & Johanson, 1977; but see Brysbaert, 1994). Furthermore, cone receptor density changes rapidly over the central 2°, falling approximately 5-fold (Østerberg, 1935), with inevitable consequences for visual acuity (Hilz & Cavonius, 1974). This means that stimuli in the present studies observed closer to the centre of gaze than the intended 2° will be far more rapidly and easily resolved than otherwise. Consequently, although the presence of non-central fixations with instructions alone did not alter the size of the RVF advantage observed when central fixations were ensured in our experiments, it is unlikely that this pattern of performance was subserved by the same processes in both cases. In particular, the RVF advantages observed when instructions alone were given are likely to have been contaminated by performance with words projected to both hemispheres when fixations fell close to target items (i.e. when fixations fell in peripheral locations) and contaminated more generally by performance with words that enjoyed greater visual acuity when presented to the right of the central fixation point.

However, the findings of Experiment 3 suggest that the effects on performance produced by non-central fixations are far from straightforward. In particular, relative to performance with central fixations, shifts in fixation location substantially affected performance with RVF stimuli, whereas performance with LVF stimuli showed little change. One potential explanation of this difference is that recognition of lateralized stimuli is dominated by different types of visual information in each visual hemifield. Although the spatial codes underlying visual word recognition have yet to be determined (see Allen, Wallace, & Weber, 1995; Jordan, 1990, 1995; Jordan & Bevan, 1994, 1996), there is some evidence to suggest that the left hemisphere is predisposed to functions based on higher-spatial-frequency information, whereas the right hemisphere is predisposed to functions based on lower-spatial-frequency information (for reviews, see Christman, 1989; Sergent, 1987). Consequently, when fixations occurred to the left and right of centre in our experiments, performance with LVF stimuli may reflect the dominance of low-spatial-frequency information for perception of LVF stimuli and the availability of this information across a range of retinal eccentricities. In contrast, performance with RVF targets may reflect the importance of high-spatial-frequency information for left-hemisphere processes of word recognition and the limited range of retinal eccentricities over which this can be encoded.

An alternative (although not necessarily unrelated) explanation of the asymmetrical effect of non-central fixations is that the right hemisphere is generally superior at pre-processing stimuli of reduced legibility. For example, Bryden and Allard (1976) found that although many typefaces produced an RVF advantage, this advantage was removed when less legible typefaces were used. Bryden and Allard argue that these results suggest that whereas legible stimuli are processed more efficiently by the left hemisphere, the right hemisphere is better able to preprocess degraded stimuli into a more intelligible form, which is then used for recognition. Consequently, when fixations occurred to the left and right of centre in Experiment 3, the absence of effects on performance with LVF stimuli may reflect the superior preprocessing of the right hemisphere and the availability of this preprocessing across a range of retinal eccentricities. In contrast, the substantial effects of non-central fixations on performance with RVF targets may reflect the absence of pre-processing for left-hemisphere word recognition and the greater reliance, therefore, of left-hemisphere recognition on stimulus legibility,

Resistance of LVF performance to shifts in fixation location also helps explain why the same-sized RVF advantage was produced when central fixations were ensured, as in conditions when unintended rightward fixation biases occurred (i.e. the "instructions-only" conditions of Experiments 1 and 2). When instructions only were given, the majority of non-central fixations fell 0.25° or less from the central fixation point (82% in Experiment 1, 95% in Experiment 2), which, from the findings of Experiment 3, produced only marginally better performance with RVF stimuli and did not affect performance with LVF stimuli. However, fixation shifts of 0.25° do alter acuity. Consequently, the same-sized RVF advantage observed when central fixations were ensured and when rightward fixation biases occurred may reflect the adaptability of LVF word recognition to shifts in fixation rather than functionally identical RVF advantages. We are currently investigating the contributions of different types of visual information to word recognition when non-central fixations occur. In the meantime, the possibility that shifts in fixation location implicate different perceptual processes is clearly problematic for studies that do not ensure central fixation when using lateralized stimuli to investigate hemispheric asymmetry.

Although the findings of Experiment 3 show that the size of the RVF advantage for words is substantially affected by shifts in fixation location, other phenomena may be even more susceptible to lack of fixation control. For example, a number of studies have investigated effects of string length on the RVF advantage. Young and Ellis (1985) found that increasing the number of letters in words had little effect on performance in the RVF but a substantial effect on performance in the LVF. This finding leads to the conclusion that each hemisphere is differentially susceptible to changes in word length. Later studies failed to replicate the length effect, casting some doubt on its validity (see e.g. Eviatar & Zaidel, 1991; Schwartz et al., 1987). However, although the ensuing debate has raised a number of theoretical and methodological issues, none of these studies ensured central fixations using an eye tracker, raising the possibility that the variability of the length effect across experiments simply reflects variations in fixation location. Indeed, wherever disagreements exist in the literature and fixation location has not been ensured (see e.g. Chiarello et al., 1986, and Sergent, 1984, on the effects of varying stimulus quality on the direction and magnitude of visual field differences; see also Chiarello, 1988, for a discussion of the effect of word class on the magnitude of the RVF advantage), different findings may reflect variations in fixation location rather than differential hemispheric specialization. As a general caveat for studies of hemispheric asymmetry, therefore, inadequate controls for ensuring central fixation may provide varying and contradictory data, which lead the theorizing astray.

In summary, we have argued that procedures that do not use an eye-tracking device to control fixation location in studies of visual field asymmetry do not adequately ensure that central fixation takes place. We have demonstrated empirically that the popular procedure of merely instructing participants to fixate dramatically fails to ensure central fixation, although the presence of non-central fixations was otherwise disguised because both procedures produced similar RVF advantages in overt preformance. However, the substantial effect on performance of fixation deviations of just 0.5° or less was revealed by systematically manipulating fixation location. The indication is clear: studies of lateralized stimuli can subserve meaningful inferences about cerebral asymmetry only if fixation accuracy is ensured by use of an eye-tracking device. Without this control, insidious influences of non-central fixations may impede our understanding of cerebral specialization.

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Original manuscript received 4 September 1996
Accepted revision received 23 June 1997