LATERALITY, 2006, 11 (4), 373–393

Psychology Press
Taylor & Francis Group

The divided visual field paradigm: Methodological considerations

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The divided visual field methodology has been used to examine a wide variety of lateralised processes. When conducting such studies it is important to employ a number of strict controls in order to maximise the effectiveness of the paradigm for examining the processing of stimuli by each hemisphere. The use of these controls is discussed in this paper. The following issues are discussed: selection of participants; methods of fixation control; presenting stimuli unilaterally; methods of responding; and measures that can be taken. The use of the divided visual field paradigm to examine interhemispheric cooperation is also discussed. Employing the recommended controls provides an effective and relatively easy method of examining the role of each hemisphere in the processing of stimuli.

Since the work of Broca at the end of the nineteenth century (see Joynt, 1964, for a review of Broca's work) it has been widely accepted that the two cerebral hemispheres are differentially specialised for processing distinct forms of information. Much of the early work examining these hemispheric specialisations used clinical participants, such as split-brain patients (e.g., Levy & Trevarthen, 1976) or patients suffering from unilateral brain lesions (e.g., DeRenzi & Spinnler, 1966). Although this work provided great advances in understanding how the brain is lateralised, it has somewhat limited ability to provide valid extrapolations to non-clinical populations. More recently, research methodologies have been developed that have enabled the examination of lateralised processing in non-clinical participants, e.g., neuroimaging techniques. However, the use of neuroimaging equipment is costly and not widely or easily available to all researchers. In contrast, the divided visual field (DVF) methodology provides an easy way of examining lateralisation that is accessible to all researchers.

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I would like to thank Claude Braun and an anonymous reviewer for helpful and insightful comments on an earlier draft of this paper.

http://www.psypress.com/laterality DOI: 10.1080/13576500600633982

The logic behind DVF methodology is that a stimulus presented to one visual field is initially received and processed by the contralateral hemisphere (Beaumont, 1983). Therefore a stimulus presented in the left visual field (LVF) is initially received and processed by the right hemisphere (RH), and a stimulus presented in the right visual field (RVF) is initially projected to and processed by the left hemisphere (LH) (see Figure 1). As such, any visual field effects identified may be taken to reflect early distinctions in hemispheric functioning. This method of investigating functional hemispheric asymmetries has been deemed both effective and efficient (Mondor & Bryden, 1992; see Lindell & Nicholls, 2003). However, in order to achieve unilateral presentation using the DVF methodology a number of factors need to be strictly controlled.

Before discussing these factors it is important to note one vital methodological consideration: the participants. First it is important to screen participants for any visual problems or neurological damage. Second, although patterns of lateralisation are relatively consistent across the

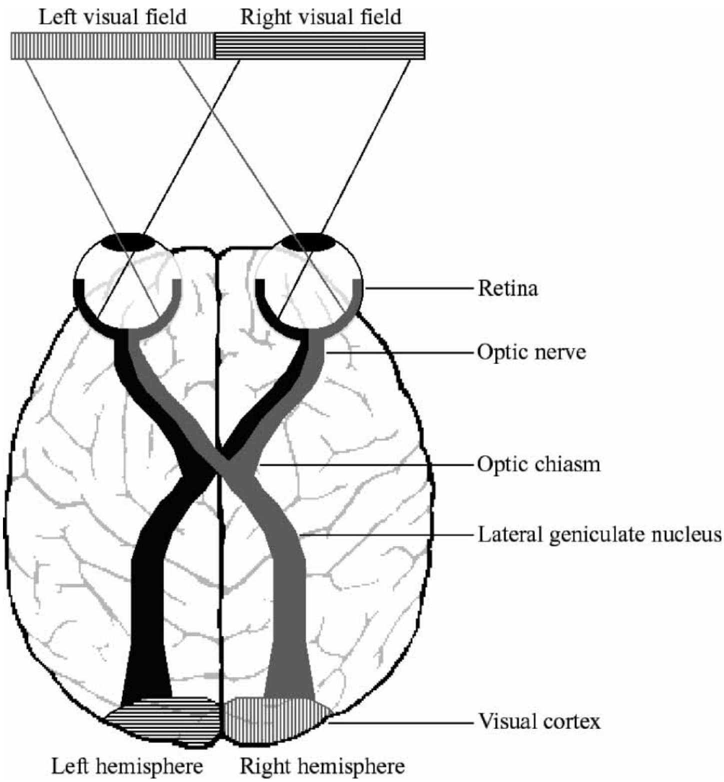

Figure 1. A schematic representation of the neuroanatomical organisation of the visual pathways.

population, they are not universal. When considering lateralised processes it is important to identify individuals with atypical patterns of asymmetry, as these individuals will provide data that are anomalous with respect to the majority of the population. One of the simplest ways of identifying such individuals is to restrict the participants to right-handers. Previous research has found patterns of lateralisation to be far more consistent in right-handers than in left-handers. For example, a functional magnetic resonance imaging (fMRI) study (Pujol, Deus, Losilla, & Capdevila, 1999) found that 96% of right-handed people were lateralised to the LH for language processing, with the remaining 4% bilaterally distributed. For left-handed people this trend was reduced, with 76% being lateralised to the LH for language function, 10% lateralised to the RH, and the remaining 14% bilaterally organised. It is therefore recommended that participant groups be restricted to those that are strongly right-handed in order to reduce possible contamination of the data by participants with atypical asymmetry.

Handedness can be assessed easily using a simple questionnaire that can be completed in a few minutes. One frequently used handedness questionnaire is the Edinburgh Handedness Inventory (Oldfield, 1971). This questionnaire comprises 10 items. In each item a task is described (e.g., throwing) and participants have to make a binary response to say which hand they use to complete the task. Using this method of handedness assessment, any participant completing eight or more tasks with their right hand would be deemed strongly right-handed and would be suitable for inclusion in a study of laterality.

The Edinburgh Handedness Inventory has been found to have high test–retest reliability (Dorthe, Blumenthal, Jason, & Lantz, 1995) over periods of up to 18 months (Ransil & Schachter, 1994). Although reliable, the Edinburgh Handedness Inventory has been criticised for treating handedness as dichotomous—treating people as either right-handed or left-handed (Bishop, Ross, Daniels, & Bright, 1996). Furthermore, it has been found that the Edinburgh Handedness Inventory is only reliable in assessing cases of extreme handedness (Verdino & Dingman, 1998) and becomes unreliable when assessing cases of mid-range handedness (Schachter, 1994). Other researchers have suggested that handedness should be considered on a continuum (Annett, 1985) or as subgroups (Peters & Murphy, 1992). Handedness questionnaires developed more recently have measured handedness on a continuum. For example, Dorthe et al. (1995) used a 7-point Likert scale with preference scores ranging from –3 ("Always with left hand") through 0 ("Equal or no preference") to +3 ("Always with right hand"). Measuring handedness on a continuum is particularly relevant in the light of recent evidence that the degree of handedness may be related to the magnitude of lateralisation (Papousek & Schulter, 1999). In order to select participants that are strongly right-handed a questionnaire, such as the

Edinburgh Handedness Inventory, would provide a quick and simple method of screening participants. However, studies that may wish to examine lateralisation in relation to the strength of handedness may wish to use a questionnaire that measures handedness on a continuum.

Using the DVF methodology, each trial consists of a number of events, each designed to maximise the ability to present stimuli unilaterally. In order to control for the placement of the stimuli, it is also important to control the participant's head position. This is necessary to ensure that the participant's head is a correct and constant distance away from the monitor, therefore maintaining the visual angle of stimulus presentation. This can be achieved easily with the use of a chin rest.

The DVF methodology recommended in this paper suggests four main events in each trial (see Figure 2): the first is to ensure that the participant is fixating centrally before the test stimulus is presented, the second is the presentation of the test stimulus, the third is to backward mask the test stimulus, and the fourth involves the participant's response. Backward masking is not widely used in DVF research. However, it enables greater control over stimulus presentation and is therefore recommended. Its advantages are discussed in greater detail later in this paper. Each of the events that together form the DVF paradigm requires strict methodological controls when attempting to achieve unilateral presentation and measure the response given. These will now be considered in turn.

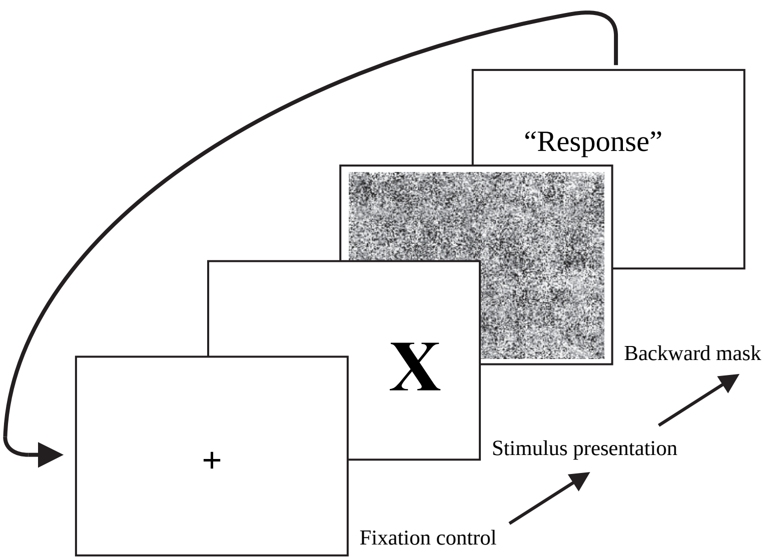

Figure 2. Graphic representation of the events occurring in each trial.

FIXATION CONTROL

In the DVF methodology the test stimulus is presented at a specified distance from a central fixation point. It is therefore important to control where the participant is fixating when the stimulus is presented to ensure that it is presented in the correct portion of the visual field. If, for example, a participant is looking to the left of the display when a test stimulus is presented, the subsequent processing of that stimulus may be affected, as it may effectively have been presented bilaterally, rather than unilaterally as intended, and any possible asymmetric effects would disappear.

A number of methods of fixation control have been used, each with varying ease and efficacy. These methods can be divided into two types: direct and indirect. The simplest and most frequently used is the indirect method of instructing the participant to fixate centrally, often using a small cross or some other marker to indicate the desired fixation point (e.g., Kitterle, Christman, & Hellige, 1990; Rapaczynski & Ehrlichman, 1979; Van Kleek, 1989; Weismann & Banich, 1999, 2000). Although some work has suggested that simple instruction may provide a reliable method of fixation control (Jones & Santi, 1978; Posner, Nissen, & Ogden, 1978), it is possible that participants may not necessarily maintain fixation, and anticipatory saccades may be initiated prior to stimulus presentation. Such eye movements may reduce the possibility of unilateral presentation. Batt, Underwood, and Bryden (1995) found that participants fixated more than 1° away from the fixation point on up to 17% of trials. Further, directional biases have been found with studies showing both rightward (Jones & Santi, 1978; Jordan, Patching, & Milner, 1998; Terrace, 1959) and leftward (Batt et al., 1995) biases. Jordan et al. (1998, Experiment 1) found that participants only fixated centrally on 23% of the trials, with 28% falling to the left of centre and 49% falling to the right of centre. It therefore seems that the indirect method of verbal instruction to fixate may not always provide adequate control over participants' fixation locations.

A further indirect method of fixation control is to present a letter or digit at the central fixation point. This letter or digit has to be reported verbally by the participant. The rationale behind this method is that the participant has to be fixating the digit or letter in order to report it, and therefore will be fixating centrally when the test stimulus is presented. If the fixation target is incorrectly reported then central fixation cannot be assumed and the subsequent response to the trial should not be included in the analyses. This method of fixation control has been used in a number of studies (e.g., Belger & Banich, 1998; Bourne & Hole, 2006; Leehay, Carey, Diamond, & Cahn, 1978; Luh & Levy, 1995). Although this method provides more control than the simple instruction method, two possible limitations have been identified (Jordan et al., 1998). First, it is assumed that the fixation target can only be reported when fixation is central. However, if the target can be reported when in peripheral vision, central fixation may not be guaranteed. This may become particularly problematic following a number of trials if there are possible practice effects. Second, it is possible that the fixation task may interfere with the response to the experimental test stimulus. For example, asking a participant to report a letter as a fixation control may have a subsequent effect on responses to the test stimulus if it is a word-based task, such as a word–nonword distinction. This possibility has been examined by Carter and Kinsbourne (1979) who found that changes to the fixation control target changed the patterns of asymmetry identified.

Direct methods of fixation control can resolve some of the methodological and theoretical difficulties encountered by the indirect methods. Direct methods involve delaying the presentation of the test stimulus until the participant is fixating centrally. The simplest direct method involves the experimenter observing the participant's eye movements and presenting the test stimulus when the participant is judged to be fixating in the desired location (e.g., Deruelle & de Schonen, 1998; Marzi & Berlucchi, 1977; Mohr, Pulvermuller, Rayman, & Zaidel, 1994). However, this method is highly dependent on the experimenter's subjective decisions about the participant's fixation locations.

A more precise direct method involves the objective monitoring of eye movements to ensure that stimulus presentation only occurs if the participant is fixating centrally (e.g., Christman, 1990; Hardyck, Chiarello, Dronkers, & Simpson, 1985). Such monitoring can be achieved using either eye-tracking equipment or electro-oculography. This method overcomes some of the limitations associated with the previous methods discussed because (a) central fixation can be ensured, (b) the participant does not have to complete the additional task of reporting a fixation control digit or letter, and (c) it is not dependent on the experimenter's subjective decisions. It therefore seems that the most effective method of fixation control is to objectively monitor eye movements and control test stimulus presentation. However, this method involves costly equipment, is more time consuming in terms of experimental preparation and the running of participants, and is less flexible in terms of the participants that may be used (e.g., the use of eye-tracking equipment may be unsuitable when using children or certain patient groups as participants). Thus, it is preferable to monitor eye movements and stimulus presentation using either eye-tracking equipment or electro-oculography. However, the alternative method of monitored central fixation may also be deemed adequate and effective.

PRESENTING STIMULI UNILATERALLY

When presenting a stimulus unilaterally there are two important factors that need to be taken into consideration and experimentally controlled: the placing of the stimulus in the visual field and the exposure duration of the stimulus. These will now be discussed in turn.

When deciding where in the visual field to present stimuli, the neuroanatomy of the visual system must be taken into consideration. The nerve fibres of the primary visual system are organised in such a way that stimuli received by the nasal hemiretinae are projected to the contralateral hemisphere, whereas stimuli received by the temporal hemiretinae are projected to the ipsilateral hemisphere (see Figure 1). However, the ipsilateral and contralateral projections are not neatly divided and a certain amount of overlap occurs between the visual fields as a result of crossover in the commissural connections in the corpus callosum (Stone, Leicester, & Sherman, 1973). Therefore, in order to maximise the chances of unilateral presentation, it is important to present stimuli outside this region of overlap. However, there has been some disagreement as to how wide this region may be, and consequently where stimuli should be presented. Estimates of the size of this bilateral strip range from 0.5° wide (Wyatt, 1978) to 3° wide (Bunt, Minckler, & Johanson, 1977). Recently it has been suggested that, at least behaviourally, the bilateral strip does not exist. Rather, that the fovea is vertically split, with each hemi-fovea projecting to the contralateral hemisphere (Lavidor & Ellis, 2003). However, Lindell and Nicholls (2003) suggest that this finding should be treated with caution and offer a wide range of evidence supporting bilateral projection of stimuli presented foveally (for more detail see Lindell & Nicholls, 2003). In order to avoid potential problems of bilateral presentation of stimuli, previous papers have recommended that a stimulus be presented with the inside edge at least 2° from central fixation (Young, 1982). However, given that some research estimates that stimuli can be projected up to 3° from central fixation (Bunt et al., 1977), this paper gives a slightly more conservative recommendation of presenting a stimulus with its inside edge 2.5–3° from central fixation.

One potential issue when presenting stimuli unilaterally in peripheral vision is the decrease in visual acuity with increasing eccentricity (e.g., Østerberg, 1935). Thus stimuli presented at different distances from fixation are not perceptually equivalent. Along with controlling the distance of the inside edge of the stimulus from central fixation, it is also important to consider how wide the stimulus is. The outside edge of a stimulus is perceived with lower visual acuity, which may have serious consequences for the processing of that stimulus, particularly for stimuli such as words.

Whether stimuli are perceptually equivalent depends on both their position in the visual field and the properties of the monitor used to display them. The position of the stimulus in the visual field is important due to the heterogeneity of retinal sampling discussed above. Changes in peripheral acuity are not symmetrical, with nasal peripheral acuity poorer than temporal peripheral acuity (Regan & Beverley, 1983; both are represented in Figure 3). The properties of the monitor will limit the resolution at which stimuli can be presented; this is particularly important if stimulus presentation is at a resolution lower than visual acuity. Take, for example, a monitor with a display resolution of 800×600 pixels, subtending 30° horizontally in the participant's visual field. This monitor would therefore be able to display stimuli at a resolution of 27 pixels per degree; therefore the maximum spatial frequency that could be displayed by the monitor would be 13.5 cycles per degree (cpd). Peripheral vision would only limit the sampling of stimuli when presented at an eccentricity where acuity is below 13.5 cpd. If we assume a foveal acuity of 60 cpd (Curcio, Sloan, Kalina, & Hendrickson, 1990) and calculate peripheral acuity using values and equations taken from Rovamo and Virsu (1979), it can be seen that acuity only falls below 13.5 cpd at

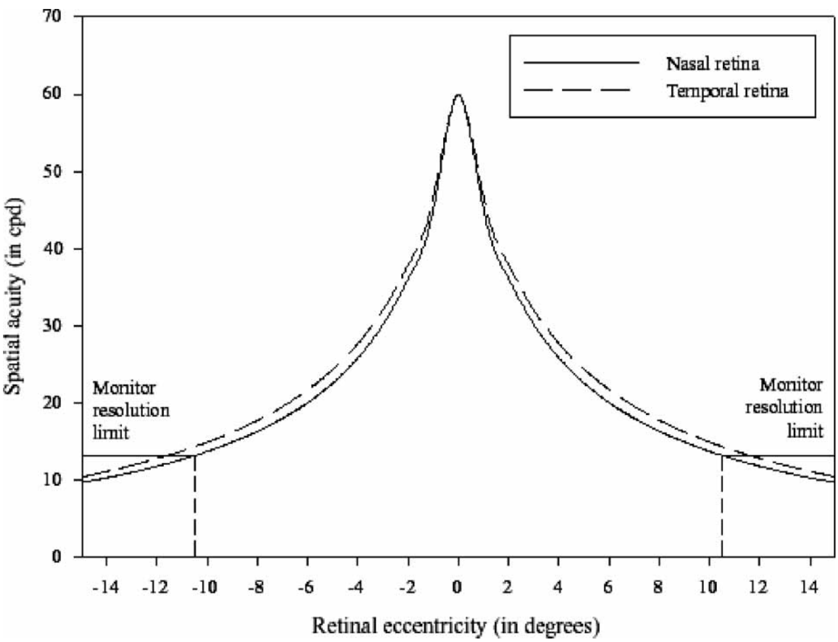

Figure 3. Spatial acuity as a function of eccentricity for both nasal and temporal retinae. Acuity was calculated using values and equations taken from Rovamo and Virsu (1979) and assuming a central acuity of 60 cpd (Curcio et al., 1990). The maximum spatial frequency that could be displayed by the monitor in the example given in the text would be 13.5 cpd (as shown by the bold solid line) therefore any stimuli presented within 10.5° from fixation (as shown by the bold dashed lines) would be sampled by the visual system with equivalent acuity.

eccentricities of greater than 10.5° from the central fixation point (see Figure 3). Therefore any stimuli presented within 10.5° of fixation would be limited by the resolution of the monitor and thus perceived with the equivalent acuity of 13.5 cpd.

The decrease in visual acuity with increasing eccentricity from the central fixation point should be taken into consideration when designing a DVF experiment that involves presenting word stimuli. With the exception of a few languages, such a Hebrew and Chinese, words are typically read from left to right and a strong bias exists for looking at the left end of a word (Pynte, Kennedy, & Murray, 1991). This may introduce a bias in DVF experiments that involve words, as the beginning of words presented in the LVF is perceived with poorer visual acuity than the beginning of words presented in the RVF. It is therefore important to take into account possible lateralised biases in the processing that may be introduced as a result of reduced visual acuity in peripheral vision, and consider alternative methods of presentation. For example, words may be presented vertically rather than horizontally (e.g., Eviatar, 1999).

The duration for which stimuli are displayed is also important in successfully achieving unilateral presentation. Whichever method of fixation control is used, it is assumed that the participant is fixating centrally when the test stimulus is presented. In order to maintain unilateral presentation the stimulus presentation should be completed before an eye movement towards the stimulus can be executed and the stimulus is fixated upon. Saccades are rapid, ballistic eye movements that move the fovea (the region of highest visual acuity) towards the target stimulus (Westheimer, 1973). Mean saccadic latencies range from 150 ms to 200 ms (Carpenter, 1988) with less than 2% of latencies falling below 150 ms. Therefore stimulus presentation needs to be completed within 150 ms in order to minimise the possibility of the test stimulus being foveated, which would cause the stimulus to be presented bilaterally rather than unilaterally. Previous papers have suggested that stimulus exposures of up to 200 ms may be acceptable (Young, 1982). However, it is recommended that stimulus presentation is limited to a maximum exposure of 180 ms, with exposure ideally limited to 150 ms if the task is a simple one.

Although saccade latencies typically range from 150 ms to 200 ms, anticipatory saccades may jeopardise the unilateral nature of the stimulus presentation and should therefore be considered. Anticipatory saccades have latencies of less than 100 ms (Bronstein & Kennard, 1987), and therefore, if initiated, may enable the test stimulus to be fixated and therefore presented bilaterally. Anticipatory saccades may occur if the location of the target stimulus is predictable and if there is a gap between the fixation control and the presentation of the target stimulus (Carpenter, 1988). Therefore visual field of presentation must be randomised in order to reduce the participant's ability to predict the visual field of presentation for the following trial and the presentation of the target stimulus must immediately follow the fixation control. Using these two controls the likelihood of anticipatory saccades will be greatly reduced.

BACKWARD MASKING STIMULI

One further control can be included in an attempt to limit the presentation of the stimulus to the desired duration. Following presentation the participant may experience afterimage effects, either resulting from their own subjective afterimage or, for some monitors, phosphor persistence (see Felsten & Wasserman, 1980; Kahneman, 1968; Van Kleek, 1989). Introducing a backward visual mask immediately following stimulus presentation ensures that such afterimage effects will not occur and that the exposure duration of the stimulus is controlled (see Enns & DiLollo, 2000, for more detail about backward visual masking). If a mask were not used then it is possible that an afterimage may occur, effectively extending the presentation duration beyond that recommended above in an uncontrollable manner.

METHODS OF RESPONDING AND MEASURES TAKEN

Two main methods of responding have been used in the DVF paradigm: verbal (e.g., Klein, Moscovitch, & Vigna, 1976; Leehay et al., 1978; Marzi & Berlucchi, 1977) and manual responding (e.g., Brown, Jeeves, Dietrich, & Burnison, 1999; Mohr, Pulvermuller, Mittelstadt, & Rayman, 1996; Schweinberger, Baird, Blumler, Kaufmann, & Mohr, 2003). From these responses latency and/or accuracy can be measured. Each method of responding has distinct advantages and disadvantages. From manual responses it is possible to take precise measurements of both the speed and accuracy of responding. However, the types of responses that can be given by the participant are typically limited to go/no-go responding or forced choice binary decisions (e.g., yes/no, word/nonword, famous/not famous). Verbal responding is far more flexible in terms of the types of responses that a participant can make (e.g., reading out a word or giving the name of a face presented). However, it may be difficult to record reaction times with high accuracy from verbal responses.

With both methods of responding there is an assumption that the response will not influence the measurement of hemispheric differences; however, this is not necessarily this case (Beaumont, 1983). For example, it is possible that, as language is LH dominant, verbal responding may lead to an overestimation of the performance of the LH. One example of this is work by Marzi and Berlucchi (1977), who conducted a DVF study examining the lateralisation of face processing. In this study participants responded verbally by giving the name of the person shown in each trial. As face processing is lateralised to the RH (e.g., DeRenzi, Faglioni, & Scotti, 1968) such a task would be expected to elicit a LVF-RH advantage. However, Marzi and Berlucchi found a RVF-LH advantage for the task. They argue that the LH advantage for the task was due to the identification nature of the task. However, the possibility that it arose from the verbal responding cannot be discounted.

The use of manual responding avoids the problems encountered with verbal responding, at least to some extent, as motor responding is not strongly lateralised to one hemisphere, but rather is represented in the contralateral hemisphere of the hand making the response (i.e., manual responses by the left hand are represented in the RH; see Rosenbaum, 1990). However, an associated problem is encountered in possible crossover effects. Manual responses are either made by responding with a left-hand response or a right-hand response, or with a left click or right click on a mouse. When combining lateralised presentation with lateralised responding it is possible that a bias may occur when the side of stimulus presentation and response is congruent (i.e., when the stimulus is presented in the LVF and the response requires a left manual response). It is therefore important to fully counterbalance both the visual field of presentation and the side of responding across participants in order to minimise any possible inflation of asymmetry effects. In addition to counterbalancing, the hand with which the response is made should be included as a factor in subsequent analyses of the data and any possible effects of hand of responding can then be examined more explicitly.

Possible laterality biases induced by unimanual responding may also be reduced with bi-manual responding (i.e., responding to a stimulus by pressing a button with each hand), although this method may only be suitable with simple reaction time or go/no-go responses. Using this method of responding, participants are asked to respond to a stimulus by using, for example, the index finger on both hands. Both reaction times are recorded and the fastest response is then used in subsequent analyses.

When designing a DVF experiment, the choice of response will be determined largely by the experimental hypotheses. However, needless complexity should be avoided and the simplest method of responding selected. The least complex response to a stimulus is a simple reaction time, followed by a go/no-go response, and then a forced choice decision. If the experiment requires more than one form of response (e.g., press one key for a "yes" answer and a different key for a "no" answer) the participant's responses may also be confounded by differences between response keys (e.g., if the reaction time recording from one key is more accurate than the other key). These possible differences can be reduced by counterbalancing the key of response between participants (e.g., half of the participants press the left key for "yes" and the right key for "no" and the other half press the right key for "yes" and the right key for "no") and can also be accounted for in the analysis of data collected.

DESIGN AND ANALYSIS OF A DVF EXPERIMENT

While researchers using the DVF are often primarily interested in laterality effects, they are also often interested in additional experimentally manipulated variables. Having taken great pains to ensure that the stimuli presented in each visual field do not differ systematically, the same fastidious approach should be taken with other independent variables. The ideal solution is to use the same stimuli in each experimental condition, but to vary the task that the participants have to complete. However, this is often not possible, and in these instances psychophysical properties should be comparable across conditions. For example, if hemispheric specialisations in processing familiar and unfamiliar faces are to be examined, both sets of faces should be equivalent in terms of luminance, contrast, spatial frequency, etc. With such controls implemented, conclusions can be drawn regarding the cognitive process in question (e.g., familiar face recognition) without the possible confound of lower-level processes. A similar problem may occur if the difficulty of the task varies across conditions; for example, if the successful categorisation of a face as familiar elicits far more errors than categorising a face as unfamiliar. When designing the experiment, try to ensure that the difficulty of the task is comparable in all conditions. Alternatively, in some experimental designs it is possible to implement an algorithm that modifies the difficulty of the task so that the error rate is constant throughout the experiment.

It is also important to consider which event triggers the following trial. One possibility is for each trial to commence at a set inter-stimulus interval; however, this method may be problematic. For example, if a participant makes a response that is longer than the inter-stimulus interval, the data for that trial may not be recorded. Such a response might also impact on the participant's response in the subsequent trials. It is recommended that each trial be initiated at a set interval following the participant's response to avoid missed trials or contaminated responses.

Typically, two types of data are collected from DVF experiments: speed and accuracy. Appropriate analyses of these data require careful consideration. Following data collection it is important to categorise all responses. Broadly, this involves categorising responses as either correct or incorrect. There may be different types of errors: decision errors (an incorrect response), not responding to a stimulus (an omission error), or responding too quickly (an anticipation error). Usually omission and anticipation errors are infrequent and can be discarded from subsequent analyses. However, if there are a large number of omission and/or anticipation errors, these should be subjected to statistical analyses.

The measurement of error is often quantified as the number or percentage of errors made. However, in some paradigms, such as one using a forced choice binary decision, a wider range of possible responses can be made, and more sophisticated methods exist that can be used to analyse all types of response. While it is often assumed that there are only *correct* and *incorrect* responses, responses can actually be categorised into four types. Say, for example, that participants are asked to classify a string of letters as a word or a nonword. They may correctly categorise a word as a word (a hit), correctly categorise a nonword as a nonword (a correct rejection), incorrectly categorise a word as a nonword (a miss), or incorrectly categorise a nonword as a word (a false alarm). In this situation it may be preferable to use the signal detection theory measure of d′, which takes into account all four possible responses, rather than a simple error rate (for more information on the signal detection method of analysis see Swets, Dawes, & Monahan, 2000).

When analysing reaction time data, the responses should also be split into correct and incorrect responses, or into the four response types if using signal detection theory. Reaction times within each condition are then often summarised by calculating the mean reaction time in that condition. One common difficulty that can occur with reaction time analysis is that they tend to be asymmetrically distributed. An extra complication can occur as this asymmetry may be exaggerated in more difficult conditions. This can be addressed by using either medians or trimmed means to summarise reaction times within each condition, or by log transforming the mean reaction times (for more detail see Ratcliff, 1993).

The data acquired from DVF experiments is most often analysed using analysis of variance (ANOVA). In its simplest form the analysis will require a two-way ANOVA, with visual field of presentation forming one independent variable, and the experimental manipulation as another independent variable. It may also be of interest to include other independent variables in the analysis, such as hand/key of responding or other factors that maybe of interest (e.g., sex of the participant if a possible sex difference in the task is expected).

PRACTICAL AND ENVIRONMENTAL CONSIDERATIONS

Having taken precautions to ensure effective unilateral presentation of stimuli using the DVF paradigm, it is important to ensure that other factors (such as the monitor used to present stimuli or the experimental room) are controlled with equal consideration. When running a DVF experiment, the primary aim will be to compare responses to stimuli presented in each visual field. It is important to ensure that stimuli presented in one visual field do not differ systematically from those presented in the other visual field. It is important that stimuli are presented equidistant from the central fixation point in both visual fields. Even when a computer program controls stimulus placement, the accuracy with which the stimulus is positioned (i.e., the distance between central fixation and stimulus presentation) should be manually checked and, if necessary, adjusted. When using a cathode ray tube monitor (for a more detailed discussion of lateralised biases that may be induced when using a cathode ray tube monitor see Ratinckx, Brysbaert, & Vermeulen, 2001), there can be variation in luminance across the screen. This might pose a problem in the DVF paradigm if one side of the monitor is brighter, as this may artificially bias laterality effects. Luminance irregularity tends to be greatest while the monitor is warming up, so it is advisable to leave the monitor on for as long as possible prior to testing a participant. Once the monitor has warmed up, luminance can be tested using a photometer to ensure equal luminance across the screen.

When designing stimuli it is important to consider how certain choices might affect the DVF paradigm. It is preferable to use a black, or dark-coloured, stimulus against a white luminant background. Leakage of light may occur if presenting a white stimulus against a black background, effectively increasing the size of the stimulus, which may be problematic when trying to control the eccentricity and size of stimulus presentation. It is important to bear in mind display time limitations when using a cathode ray tube monitor. It only takes microseconds for each line of pixels to refresh, but if the stimulus is excessively large there is a risk of introducing a bias in stimulus presentation, as the left side of the monitor displays slightly before the right side, and the top displays slightly before the bottom. To avoid this possible confound, use small stimuli.

It is preferable to run the experiment in a darkened room. Ensure that the participant has a few moments with the lights dimmed, or off, before beginning the experiment to ensure that their retinae have adapted to the level of light (for a recent review of dark adaptation see Lamb & Pugh, 2004). It is also important to make certain that ambient light is equalised on either side of the participant (e.g., light from a door, window, or light) to avoid biasing any lateralised presentation of stimuli or responding.

When participating in a DVF experiment, some individuals may need to blink a great deal due to either dry air or constant gazing and concentration (particularly if wearing contact lenses). This can be uncomfortable for the participant and may lead to missed trials. Placing a wet sponge at the foot of the chinrest can easily solve such a problem.

USING DVF METHODOLOGY TO EXAMINE INTERHEMISPHERIC COOPERATION

Whilst the DVF methodology is useful for examining lateralised processing of stimuli, it can also be used effectively to examine the role of interhemispheric cooperation. In all studies using non-clinical participants it is likely that a certain amount of information is passed between the hemispheres in order to complete the task. Four methods of examining interhemispheric cooperation using DVF methodology have been developed, each of which will be discussed (see Figure 4).

The first and oldest experimental approach that has been used to examine interhemispheric cooperation, and one that is still used today, is the Poffenberger paradigm (Poffenberger, 1912). Using this method, visual targets are presented in each visual field and participants have to respond using either the hand on the opposite side to that in which the visual stimulus was presented (crossed, Figure 4a right), or the hand on the same side (uncrossed, Figure 4a left). The rationale behind this method is that responding in the uncrossed condition requires processing from only one hemisphere, whereas responding in the crossed condition requires transfer of information from one hemisphere to the other. Therefore, the crossed–uncrossed difference can be used as an estimate of the amount of time it takes for information to be transferred from one hemisphere to another. A recent study, using event-related fMRI, has provided evidence for transfer of information across the corpus callosum for the crossed–uncrossed difference (Weber et al., 2005).

The second method of examining interhemispheric cooperation is the redundant target paradigm. This method has developed from a classic finding that a participant will respond faster to two simultaneously presented copies of the same stimulus (Figure 4b right) than to a single copy (Figure 4b left; Todd, 1912). Although participants are presented with the same information in both conditions, when presented with an additional "redundant" copy, reaction times are facilitated; hence this is known as the redundant target effect, or redundancy gain. This paradigm can be used to investigate interhemispheric cooperation by comparing reaction times to a single copy presented in one visual field to reaction times to two copies, where one copy is presented in each visual field. In the redundant target condition, faster reaction times are attributed to interhemispheric cooperation. This suggestion is supported by studies that have shown an increased effect of redundancy gain in split-brain patients (Corballis, 1998; Reuter-Lorenz, Nowaza, Gazzaniga, & Hughes, 1995).

The third method, developed by Dimond and Beaumont (1972), involves a simple comparison between the processing of pairs of stimuli presented unilaterally (Figure 4c left) and the processing of pairs of stimuli presented

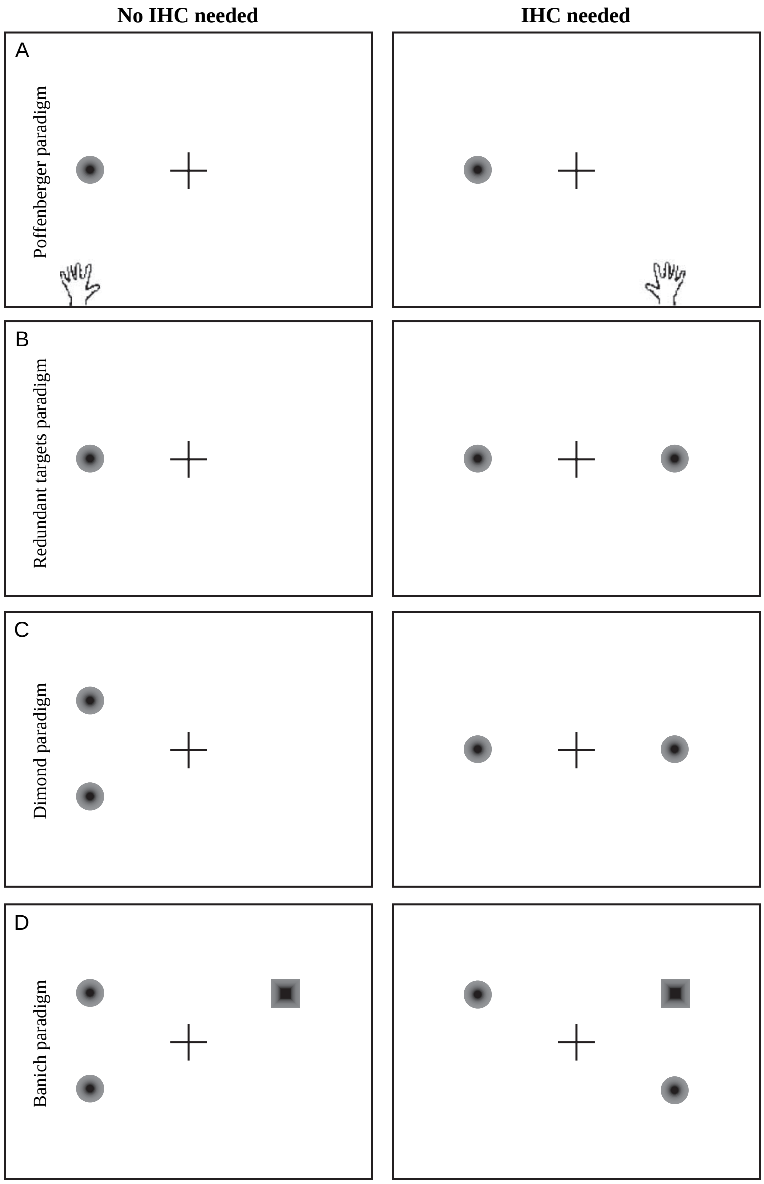

Figure 4. Four experimental paradigms that can be used to examine interhemispheric cooperation (IHC). For each paradigm the left panel shows the condition in which IHC is not necessary to respond to the stimulus/stimuli and the right panel shows the condition in which IHC facilitates responding to the stimulus/stimuli.

bilaterally (Figure 4c right), where one copy is presented in each visual field (e.g., Mohr et al., 1996, Schweinberger et al., 2003). The rationale behind experiments using this methodology is that any bilateral advantage identified reflects the advantage provided by the activation of interhemispheric cooperation. Evidence in support of this can be gained from split-brain patients who do not show an advantage in bilateral trials (Mohr et al., 1994).

The final method to be discussed has been developed by Banich and colleagues (see Banich & Shenker, 1994) and has been used in a wide variety of studies using alphabetic (e.g., Weissman & Banich, 2000), geometric (e.g., Weissman & Banich, 1999), and face (e.g., Compton, 2002) stimuli. Using this paradigm, participants are presented with three stimuli: two in the top half of the display, one in each visual field, and the third in the bottom half of the display. The participant's task is to decide whether the bottom stimulus matches either of the stimuli presented above it. When two matching stimuli are presented within the same visual field (Figure 4d left), it is assumed that the hemisphere that they are presented to functions as an isolated unit to complete the task. When the two matching stimuli are presented across the two visual fields (Figure 4d right), it is assumed that interhemispheric cooperation must occur in order to complete the task. Comparing performance in each of these two conditions, any change in performance is thought to reflect the time taken for interhemispheric cooperation to occur.

When designing an interhemispheric cooperation experiment, it is preferable to select the simplest paradigm that will enable the hypothesis to be addressed. One important issue to consider and control for is the placement of the stimuli and the effect this may have on the deployment of visual attention. In the DVF paradigm, participants are required to fixate centrally prior to stimulus presentation, it is therefore difficult to discern whether an advantage for responses to centrally (bilaterally) presented stimuli in comparison to unilaterally presented stimuli results from an interhemispheric cooperation advantage or from not having to shift attention to complete the task. A similar problem may also occur if stimuli are presented at varying distances from the central fixation point, and therefore all stimuli should be presented equidistant from the central fixation point.

SUMMARY AND RECOMMENDATIONS

Strict methodological controls are necessary to maximise the validity of conclusions drawn from DVF studies. It is important to include only participants who are strongly right-handed. The use of a chin rest is necessary to ensure that participant's head movements are limited and to maintain the distance of the participant's eyes from the monitor.

Each trial within the DVF comprises a number of events (see Figure 2). First it is necessary to control the participant's fixation location prior to presentation of the test stimulus. A direct method of fixation control is recommended, using eye-tracking equipment or electro-oculography to monitor the participant's eye movements and withholding stimulus presentation until fixation is on the desired central location. Second, the test stimulus is presented. It is important that both the location and exposure duration of the test stimulus are strictly controlled in order to ensure unilateral presentation. It is recommended that stimuli be presented for 150–180 ms (with shorter exposure time if the task is a simple one), at 2.5–3° from central fixation and that presentation is followed immediately by a backward visual mask to reduce any possible afterimage effects. Visual field of presentation must be randomised to reduce the likelihood of anticipatory saccades occurring. The DVF methodology can be relatively difficult for a participant to master and may be quite tiring, particularly with more complex or difficult tasks. It is recommended that participants be given enough practice trials to become comfortable with the speed of stimulus presentation and the method of responding. Participants should also be given regular breaks, and be able to indicate easily if they need a break, in order to maintain high levels of concentration and avoid "noisy" responding. When used with appropriate controls the DVF methodology provides and effective, inexpensive, and relatively easy way to examine the lateralisation of processing.

Manuscript received 13 May 2004
Revised manuscript received 10 January 2006
First published online 01 May 2006

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