Gaze Direction and

Two-choice Reaction Time:

Multiple Tests of a Theory

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The relationship between voluntary eye movements and cognition was examined in terms of Kinsbourne's (1972) account of conjugate lateral eye movements (CLEMs). This account is itself based upon his (1970) attentional gradient model of lateralized cerebral asymmetry. A novel methodology was devised with gaze position (GP) and visual field (VF) as the independent variables and manual reaction time (RT) as the dependant measure. A divided VF paradigm using two-choice RT tasks was used thereby avoiding the ambiguities of orthodox CLEM methods. The tasks were, letter (X,V) identification, a lexical decision using words and non-words, simple geometrical shapes, and a mental rotation task. Five visual display units (VDUs) arranged in the form of a Maltese cross subtending 50 degrees horizontally and 35 degrees vertically functioned as tachistoscopes. Trials were either randomized (R) over the VDUs or presented in blocks (B) on each VDU in turn. Under R conditions using verbal tasks, a GP x VF interaction was found for horizontal GPs. This interaction was due to RTs being fastest when the VF and GP hemispace were congruent (e.g., LVF and LGP). Under B conditions, a GP main effect was found for verbal tasks. This effect was shown by RTs being fastest when subjects looked to the right GP, both VFs producing this effect. No reliable effects were found for visual-spatial tasks. The GP effects found under B conditions were weak and inconsistent and required a form of

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meta analysis to demonstrate their reliability. No evidence
was found for an interaction of GP with task difficulty. A
number of possible explanations, including Kinsbourne's
models, were examined. The direction of the GP x VF inter-
action when trials were randomized was contrary to the
predictions made from Kinsbourne's models and the GP main
effect found under B conditions was not predicted by them;
hence "arousal" and "attention" as used by Kinsbourne were
rejected. If eye movements and cognition were regarded as a
dual task workload, then intrahemispheric interference could
account for the interaction. However, it could not account
for the GP effect under B conditions, nor could it account
for the absence of any effects with visual-spatial tasks.
Also, neuroanatomical considerations made global intrahemi-
spheric arousal and interference implausible as explanations.
One possible explanation was that under both presentation
conditions, an habitual bias towards right hemispace
occurred. But this bias could be reversed if motor interfer-
ence occurred in the left hemisphere between saccade control
and subvocalization. Interference would only occur with
randomized trials and verbal tasks, producing the GP x VF
interaction. This explanation also accounted for the absence
of any effects when visual-spatial tasks were used. The
overall results were evaluated in relation to other accounts
of CLEM production and also against modern developments in
cerebral laterality investigations.

Preface

"Eyes are more accurate witnesses than ears"
Heraclitus.

"The eye obeys exactly the action of the mind"
Emmerson.

"The organ of vision, the eye, is favoured above
all other senses in that it most clearly
expresses the state of the psyche and acts as a
mirror both of the world and of inner life."
Scheidler.

That vision is the preeminent human sensory system is shown by the fact that fully 75% of the entire brain (Woltzin, 1976, cited in Morse, 1990) and 40% of the human cerebral cortex (Findlay, 1985) is either dedicated to or involved in visual processing. This preeminence is reflected in the extent of our knowledge of the sensory systems; the basic visual system is better understood than any of the other major senses.

Eye movements are fundamental to understanding the visual system. The constant "trembling" of the eyes, (microsaccades), which is essential to allow the nervous

system continually to "read" the retinal image, shows that eye movements are a very important feature of the visual system. This importance can be seen by the fact that their study can be traced back for over 1000 years to the Arabs (Grusser, 1986; Heller, 1988), and today comprises a very large body of empirical research and sophisticated mathematical models.

Eye movements, which can be automatic or voluntary, may range in size from microsaccades to large movements that can reach the limits of mobility. One example of automatic movements is when compensating for body motion, another being the startle reflex when the eye flicks toward a sudden, novel stimulus. Voluntary movements are deliberately guided movements during, for instance, inspection, panoramic search or visual pursuit.

Studies of eye movements may be organized into several overlapping categories that span a continuum from mainly externally oriented movements to movements that primarily are associated with internal reflection. Such studies may also range from a neuroanatomical to a psychological emphasis.

At the extreme of the externally oriented studies are found investigations concerned with movements that are associated with locomotion and orientation to environmental stimuli. Studies in this area are directed at the problem of how a stable retinal image is maintained despite movements of an

observer or the observed object. These studies may deal with the movements themselves together with the associated sequence of fixations (e.g., Yarbus, 1967), model the movements within a cybernetic paradigm (e.g., Carpenter, 1977), or focus on the neuroanatomy of the oculomotor system. Buttner-Enever (1988) provides a comprehensive account of the neuroanatomy between the eye muscles and the frontal eye fields of the cerebral cortex.

The knowledge obtained from studies concerned with the stability of the retinal image provides the foundation for studies that have a more explicitly psychological thrust. Two areas readily can be distinguished. In the first, eye movements are used solely for the purpose of acquiring environmental information for concurrent cognitive processing. This occurs during visual search or inspection (e.g., Arani, Karwan, & Drury, 1984; Ellis, 1986; Matsuoka & Ueda, 1986). An important associated area of study is reading (see Rayner & Pollatsek, 1986, for a tutorial review). Another closely related area of study is the relationship between saccades and attention (e.g., Parasuraman & Davies, 1984).

A distinctly different class of eye movements involves movements that are used as a signalling system to transmit information in social interactions. In the human social context, the eyes act as important information sources in addition to their primary evolutionary function of

information gathering, a fact that is reflected in many common sayings, activities and attributions. For instance, sexual interest may be indicated by giving "the eye", intimidation by means of a "cold" or "hard" stare, being attracted by a pair of "laughing eyes", showing sadness by "walking with downcast eyes" or snubbing someone by "looking straight through them". These are ubiquitous methods of deliberate (or inadvertent) communication *via* the eyes. Personality characteristics are often inferred from "bold" stares, "honest, open" looks or a "shifty eyed" appearance. The common feature for all of these and other "eye messages" is the reliable presence of particular eye movements, particular gaze directions or, at times, the studied absence of either.

Although the origins of using the eyes to transmit information are lost in the mists of evolutionary antiquity, studying such eye movements is a recent development concerned mainly with emotional states and conversational markers. Argyle and Cook (1976) give an extensive treatment of this area while Kleinke (1986) provides a research and modelling review. A recent peripheral development is the use of dysfunctional eye movements as indicators of schizophrenia (Clementz & Sweeney, 1990; Lipton, Levey, Holzman, & Levin, 1983).

Other than when inner emotional states are being signalled, the eye movements that have so far been mentioned all occur

in situations where external stimulation plays a large if not major role in determining the particular movements. There are, however, classes of eye movements that occur with little if any external input. An intensively studied class is the rapid eye movements that occur during sleep (reviewed by McGrath & Cohen, 1978). Another class is those movements that are made when inspecting internally generated visual images (Hebb, 1968). This latter class is closely related to the eye movements that form the focus of this dissertation, namely, those eye movements that occur when an individual is engaged in reflective thought. Specifically, the movements that occur when engaged in deliberative cognition, as distinct from daydreaming, and which may be indicators of, or facilitators of, specific cognitive functions.

This is the claim made in the opening quotation by Scheidler (p. 1 of this dissertation), namely, that the eyes act as a mirror to inner life, and, by extension, that eye movements are directly related to thought processes. The relationship between eye movements and cognition is a relatively unexplored area and much of the work is unreliable and contradictory. This dissertation is an attempt to clear up some of the sources of contradiction and establish whether or not some eye movements might reliably be related to cognitive processes in a causative rather than a consequential manner.

This dissertation is unusual in three respects. A complex experimental programme combined with weak experimental

effects made it difficult to interpret separately the results of the individual experiments. The effect of this was that, for meaningful discussion, the results of each experiment had to be considered within the context set by the outcomes of the others. Consequently, the discussion of each experiment serves only to maintain the threads of the theoretical rationale.

The second unusual feature is the manner chosen to present the ways in which various design and methodological issues were dealt with, the choices that were made and the subsequent effects of those choices. These have been brought together into the section entitled, Problems, Difficulties and Mistakes. The topics collected into that section could have been dealt with in the various sections of the dissertation to which they are immediately related. However, to deal adequately with these and several other topics, it proved necessary to write a number of essays for insertion into the appropriate sections. For instance, the statistical considerations involved in counterbalancing might be better placed in the Design section, while the reasons for choosing a particular response method properly belongs to the first Method section. However, this would have interrupted the flow of the presentation with lengthy digressions (which caused even the writer to lose the logical train of a complex programme). To avoid this irritation, the topics were brought together in the one section. This section was placed at the end of the dissertation in order that the relevance of

the topics could be readily seen in the context of the entire programme.

Thirdly, the use of the *alpha* level is unconventional. Since the programme was exploratory and because any effects were expected to be small, strict adherence to the conventional 0.05 significance level may have led to interesting effects being discarded. Instead, the approach advocated by Eysenck (1960) was adopted where the actual probability of an effect becomes only one of several factors determining acceptance or rejection of the effect. In short, scientific judgement was the criterion for accepting the reality and importance of any effects.

Introduction

Historical outline

Scheidler's claim that the eye acts as a mirror of both the world and inner life is based on the Platonic model of visual perception which presumed that light particles are emitted by the eye (Heller, 1988). Although this model of perception has been thoroughly discredited, the possibility that eye movements may be systematically linked to intra-psychic factors has undergone a small revival over the past 35 years. In particular, considerable interest has been occasioned by the putative link between eye movements and Kinsbourne's (1970, 1972, 1973, 1975) attentional gradient model of asymmetric functional cerebral laterality effects.

The first modern author to deal with the topic was Teitelbaum (1954). In a paper that has rarely been cited, he described the differing rhythmical eye movements that occurred during various activities such as daydreaming or conversation. There was no further mention of the topic for another 10 years until Day (1964, 1967), apparently unaware of Teitlebaum's paper, reported the clinical observation that his clients were individually consistent in the direction of their eye movements during ordinary conversation, and that the preponderance of left or right movements seemed to correlate with personality variables. This observation received support from others. Duke (1968) confirmed that

individuals are consistent in their eye movements, males more so than females, and noted that reflective questions elicited more movements than simple factual ones. Bakan and Shotland (1969) found that right movers performed better on the Stroop word/colour test than left movers. Bakan (1969) reported that left movers were more susceptible to hypnosis than right movers, but that right movers scored higher on the Quantitative scale of the Scholastic Aptitude Test than on the Verbal one. Also, left movers preferred "soft" rather than "hard" subjects for their college majors. He then speculated that:

> "The relationship between laterality of eye
> movements, hypnotizability and the other
> variables described above can be considered in
> terms of the functional asymmetry of the brain.
> The right or left movements which are the subject
> of this paper are controlled contralaterally by
> activity in Brodman's area 8, the frontal eye
> fields (Robinson, 1968). It may be that the left
> or right movement associated with the reflective
> process is symptomatic of the easier triggering
> of activities in the hemisphere contralateral to
> the direction of the eye movement." (p. 790).

The importance of this idea was that, potentially, it offered a convenient indicator of hemispheric functional asymmetries. This suggestion stimulated a body of research that differed markedly from the study of individual personality correlates of idiosyncratic eye movements. Those studies, covering a wide range of personality variables, were critically reviewed by Ehrlichman and Weinberger (1978) and more recently by Hiscock (1986). The topic is only distantly related to the

research reported in this dissertation and will not be pursued further.

The other line of enquiry, deriving from Bakan's (1969) speculation, seeks to relate lateral eye movements to the lateralized cognitive functions of the brain. Eye movements that are believed to be conjugately linked to the causative activity of one or the other cerebral hemisphere are usually called conjugate lateral eye movements (CLEMs). Attention has mainly been directed at the lateralisation of verbal and visual-spatial functioning, but some interesting forays into other areas have been reported. Among these topics is ocular motility, that is, the relative frequency of CLEMs during differing cognitive processes. Other topics are the effect of emotional arousal, developmental aspects of CLEMs and the effect of deliberately varying gaze position (GP) on task performance. Eye movements in this latter situation, where GP is used as the independent variable, will be referred to as reverse CLEMs. With the exception of reverse CLEMs, the research deriving from Bakan (1969) was thoroughly reviewed by Ehrlichman and Weinberger (1978) and later extended by Hiscock (1986) and De Gennaro and Violani (1988). Only a summary and update of the main issues will be given here. A detailed examination of specific issues and a review of the literature on reverse CLEMs will be introduced later at more appropriate points.

Bakan's (1969) suggestion was elaborated by both Kocel, Galin, Ornstein, and Merrin (1972) and Kinsbourne (1972)[1], who reasoned that if CLEMs were an index of lateral functioning then the questions that subjects received should influence the directions of their CLEMs. In particular, since the left hemisphere is thought to be specialised for the use of language and abstract symbols, questions with a high requirement for language or symbol manipulation should result in rightward CLEMs. Conversely, given that the right hemisphere is believed to be specialised for visual-spatial and musical functions, questions with a high visual or musical content should result in leftward CLEMs.

Questions intended to involve predominantly left hemisphere functions are usually called verbal questions (VQs) for convenience. Some examples are: define the word "economics"; make up a word using two forms of the same verb; solve the following arithmetic problem, "144/6 x 4"; Similarly, questions intended to involve mainly right hemisphere functions are called spatial questions (SQs). Some examples of these are: "There is a profile of George Washington on a quarter. Which way does he face?"; "Try to picture all the doors in your house and tell me how many there are"; "Hum

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[1]Kinsbourne (Kinsbourne 1970, 1972, 1973, 1975; Kinsbourne & Hicks, 1978) has produced several models relating CLEMS, attention and cerebral lateral asymmetries. Testing these models is the central theme of this dissertation and frequent references will be made to Kinsbourne and his models. To smooth the flow of the presentation, except for first or specific citations of these publications, textual references will simply indicate Kinsbourne or his models.

'Row, Row your Boat'". All examples are taken from Kocel et al. (1972).

Between 1972 and 1977, 19 experiments examined the relationship between question type and the subsequent CLEM, but only nine obtained significantly more rightward CLEMs for VQs than for SQs. One obtained significantly more rightward CLEMs for SQs than for VQs, and, notably, no relationship between question type and horizontal CLEMs was found in the remaining nine experiments. These figures have been recently updated by Guastella, De Gennaro and Violani (cited in De Gennaro & Violani, 1988). Of 79 experiments reported in 62 papers, 37 found a greater proportion of right CLEMs following VQs, six found more right CLEMs following SQs and, notably, 36 found no significant differences. These figures are in essentially the same proportions as those catalogued by Ehrlichman and Weinberger (1978).

The incidence of leftward CLEMs and significance tests involving them are less well documented. Only six of the experiments reviewed by Ehrlichman and Weinberger (1978) reported significance tests, to which can be added a further seven later ones (Ahern & Schwartz, 1979; Deijen, Loriaux, Bouma, & Orlebeke, 1986; Gumm, Walker, & Day, 1982; Katz & Salt, 1981; Lefevre, Stark, Lambert, & Genesee, 1977; Raine, Christie, & Gale, 1988; Warren & Haeuter, 1981). In these 13 reports, SQs were accompanied by significantly more leftward CLEMs on five occasions, rightwards on two but with no

differences reported between the question types on the remaining six occasions.

Sixteen of the 19 experiments examined by Ehrlichman and Weinberger (1978) also reported the occurrence of upward movements and/or stares during which the eyes were stationary and centred in the head. Nine out of nine times when upward movements were reported, SQs elicited significantly more of these than did VQs. Similarly, in 10 out of 16 experiments, stares in response to SQs outnumbered those in response to VQs, in two cases they were equal and in one case the effect was reversed. In two experiments no stares were observed. Since the 1978 review, a number of other studies have also demonstrated the prevalence of stares in response to SQs (Berg & Harris, 1980; De Gennaro & Violani, 1988; Deijen et al., 1986; MacDonald & Hiscock, 1984; O'Gorman & Siddle, 1981; Reynolds, 1978). However, Ahern and Schwartz (1979) and Gumm et al. (1982) reported that stares only tended to be associated with SQs.

Three studies, covering six experiments, examined ocular motility during the processing of VQs and SQs. In the first of these, Weiner and Ehrlichman (1976) used video monitoring of subjects' eye movements, but in subsequent experiments electro-oculography (EOG) records were used (Ehrlichman & Barrett, 1983a; Hiscock & Bergstrom, 1981). All reported that ocular motility was significantly less for SQs than for VQs. Furthermore, Ehrlichman and Barrett were able

to show that SQ motilities were suppressed below a resting base line and VQ motilities were elevated above the same baseline. Reynolds (1978) found that a somewhat similar phenomenon occurred with children where latencies to the first CLEM following an SQ were much longer than for VQs. Finally, May, Kennedy, Williams, Dunlap, and Brannan (1990) using ocular motility as an index of mental workload in counting tasks, found that motility decreased as counting complexity increased, the effect occurring despite practice or additional visual demands.

In summary, most studies have reported a significant association between question type and the subsequent eye movements or fixed stares, but this association is more evident for SQs than for VQs.

There is further evidence for CLEM consistency, both individually and between subjects. Ehrlichman and Weinberger (1978) produced a frequency histogram of percent rightward CLEMs for 214 subjects used in their experiments. The distribution was essentially trimodal with the peaks occurring at the centre and to the extreme left and right of the distribution. This was interpreted as showing that not only were subjects highly consistent in their scores within a session, but that a simple division into left and right movers was inappropriate.

The consistency of individual CLEM patterns has been demonstrated in a few studies. Libby (1970) reported a split half correlation of r = 0.83 within a single session. Between session test-retest correlations have ranged from r=0.65 (Crouch, 1976) to r=0.78 (Bakan & Strayer, 1973; Etaugh & Rose, 1973). To test the consistency of CLEMs across conditions, Ehrlichman and Weinberger (1978) re-analyzed the data from Ehrlichman, Weiner, and Baker (1974) obtaining a correlation of r=0.77. Consistency across conditions was also found for Japanese subjects (Hatta, 1984).

A small number of studies have used CLEMs to investigate the putative lateralisation of emotions. Three studies found that leftwards CLEMs predominated in response to emotionally laden questions (Borod, Vingiano, & Cytryn, 1988; Schwartz, Davidson, & Maer, 1975; Tucker, Roth, Arneson, & Buckingham, 1977) but a fourth study by Ahern and Schwartz (1979) resulted in a complex CLEM/emotion interaction that was difficult to interpret.

A number of studies were specifically focused on anxiety, primarily because it has been viewed as a possible source of experimental artefact. Tucker et al. (1977) reported that induced stress resulted in more leftward CLEMs, but five subsequent experiments found no relationship between anxiety and CLEMs (Berg & Harris, 1980; Hatta, 1984; Hiscock, 1977; Lenhart, 1985; MacDonald & Hiscock, 1984). The available

evidence appears to be weighted against a link between emotion and CLEMs, but not conclusively so.

A few studies have investigated the possibility that CLEMs may emerge with maturation. Hiscock (1986) reviewed the small number of developmental studies and decided that the only justifiable conclusion was that CLEMs are infrequent among very young children.

One final experiment is of interest, both for its originality and for its isolation from the remainder of the CLEM literature. Rosenberg (1980) investigated the effect of VQs and SQs on the rates of elicited optokinetic nystagmus (OKN). OKN is a reflex eye movement that occurs in response to a moving visual field. The subject's eyes repeatedly move in the direction of the motion of the field before snapping back to the central fixation point. She found that, in comparison with right to left nystagmus, VQs increased the rate of left to right nystagmus, SQs decreased the rate, while combined VQ/SQ tasks produced an intermediate effect. Rate changes were more evident for subjects classified as right movers than those classified as left movers. This experiment demonstrated that cognitive tasks can differentially affect ongoing eye movements.

When the collective evidence for the association between question and subsequent CLEM is considered along with that for individual consistency in eye movements, Ehrlichman and

Weinberger's (1978) conclusions remain as valid today as in 1978. Firstly, there is only limited support for the laterality hypothesis. Secondly, when used as discriminatory indices, upward movements and stares perform at least as well as horizontal CLEMs in distinguishing between SQs and VQs to which can be added ocular motility as another efficient index. Thirdly, the relationship between vertical movements and SQs is more reliably found than that between VQs and lateral CLEMs, and this difference warrants further investigation.

Although there appears to be some link between eye movements and reflective thought, numerous contradictory reports occur in the literature. Ehrlichman and Weinberger (1978) consider that these are largely attributable to shortcomings in both CLEM methodology and the assumptions underlying the methods that are used. Additionally, Hiscock (1986) has drawn attention to the complete lack of any investigative strategy. A central issue addressed by this dissertation is that these shortcomings and the consequent lack of progress in CLEM research is due to investigators placing an unwarranted emphasis on a single theoretical model and its underlying assumptions combined with the deceptive simplicity of CLEM methodology.

Theoretical models

Considering the many confusing results that have been
reported in the CLEM literature, it is not surprising that
there has been little theoretical development of the issue.
Other than a theoretical speculation by Hebb (1968), only
three theoretical models have been developed to account for
those consistencies that have been found.

Hebb (1968) speculated that eye movements were made when
internal mental images were generated and inspected. This
idea received little support and was soon discarded
(Erhlichman & Barrett, 1983a) because imagery was later found
to be associated with a reduction in eye movements (Hodgeson,
1977, cited in Marks, 1983; Marks, 1973).

The most circumscribed model is an attempt to account for the
occurrence of stares in response to SQs and is based on the
ocular motility studies mentioned earlier. Erhlichman and
Barrett (1983a) suggested that a direct link exists between
the oculomotor system and the rate at which internally
generated information is sampled. In a *post hoc* explanation,
they suggest that the sampling rate of static visual images
is less than that for the ordinary ongoing random thoughts
that provide the base line condition. On the other hand, the
sampling rate for directed verbal processing is higher than
for the base condition. (One might presume that this is
because random thoughts tend to change more frequently than a

static visual image while verbal processing must occur in a rapidly changing sequence.) This results in ocular motility being depressed below base line for SQs and elevated for VQs. Unfortunately, Hiscock and Bergstrom (1981) found that a mental rotation task also reduced ocular motility below a resting base line. While the sampling rate for a static mental image might conceivably be less than that of random processes, it is difficult to understand how the rate for complex visualisations such as mental rotation can be less than that for a resting base line. The model is further weakened by the findings of May et al. (1990) where counting tasks suppressed ocular motility; counting should have increased motility because it is a presumed verbal-analytical task.

Further criticism of this model can be made on methodological grounds, specifically, the observation intervals that were used. Each of the three studies reporting on CLEMs and ocular motility used different observation intervals. Weiner and Ehrlichman (1976) used the reflective plus answering periods, where the reflective period is the interval between the end of questioning and the subject beginning to answer. Ehrlichman and Barrett (1983a) used only the answering period while Hiscock and Bergstrom (1981) chose the reflective period. This is especially important in view of the report by Wyler, Graves and Landis (1987) that those CLEMs associated with the questioning period were different to those occurring during the answering period. Thus, the model

is based on evidence that is not strictly comparable across studies. This, coupled with the dubious assumption about visual sampling rates means that the model should be regarded cautiously.

Moreover, the model is restricted in its scope; it might be inferred that the increased lability accompanying VQs might facilitate larger eye movements but the originators of the model make no mention of this possibility. The model is explicitly restricted to the association of SQs and stares, which is in marked contrast to the other two models, both of which purport to account for most types of CLEMs.

Rosenberg (1979, 1980, 1981) has proposed that CLEMs serve a facilitative function during reflective thought, this proposal being an extension of one made by Rodin and Singer (1976) and Singer (1978). These authors suggested that during reflective thought, external stimulation, especially highly relevant stimuli such as faces, competes with internal processing for a limited "channel capacity". Thus, the questioner's face, having high social salience, interferes with internal processing. By moving the eyes away from the face, this interference is "gated" out. Rosenberg extended this model to account for the various directions in which the eyes are moved. Due to the contralateral innervation of the retinal hemifields, a horizontal CLEM has two effects. Firstly, half of the visual field (VF) to one eye is occluded by the nose, which reduces the visual input to the cerebral

hemisphere contralateral to the direction of movement. Secondly, the same movement brings the entire forward field of view into the scope of the ipsilateral hemifield and thence to the ipsilateral hemisphere. Assuming that a question does activate the target hemisphere, a CLEM contralateral to that hemisphere will both reduce processing competition due to external stimuli entering the engaged hemisphere, and allow the unoccupied hemisphere to more effectively monitor the external environment. These movements are primarily learned by experience and can be influenced by longterm stable influences of the visual field. For instance, Rosenberg, Dye, Harrison, Manning, and Kazar (1983) reported that tall individuals had CLEMs that were biased upwards whereas short people had theirs biased downwards. The reason suggested for this was that those directions generally contain fewer distracting stimuli than the opposite ones given the height of the individuals involved. While the model accounts for both the occurrence and direction of most CLEMs, it is completely silent on the question of stares. Given the robustness of the results from the ocular motility studies and the prevalence of stare CLEMs, this is a definite weakness.

Rosenberg's (1979, 1980, 1981) model has received little attention. Relevant evidence is sparse and when it exists, it usually has been obtained from studies that were concerned with other issues. According to the model, CLEMs, being primarily driven by external stimulation, should occur less

frequently with normal subjects when visual stimuli are minimised and be completely absent for congenitally blind subjects. The evidence bearing on these predictions is somewhat equivocal. Takeda and Yoshimura (1979) found that CLEM frequency was reduced in the dark as did Erhlichman and Barrett (1983a) when testing the original "gating" model. However, contrary to predictions made from the gating model, the latter authors also found that ocular motility was the same for both cartoon faces and a simple oval shape. Griffiths and Woodman (1985) observed clearly distinct reflective CLEMs made by a congenitally blind subject in response to VQs and tactile analogues of SQs. Not only does this raise the question of what their subject was "gating out", but also the question of how the subject developed a range of consistent CLEMs in the first place.

The empirical evidence that is currently available suggests that the Rosenberg model has some major weaknesses. Taking theoretical considerations into account make it even less tenable. As noted earlier, the model is completely silent regarding stares in response to SQs. According to the model, CLEMs are instrumental in reducing the input to the supposedly engaged cerebral hemisphere. Since performing cognitive visual-spatial tasks is a presumed right hemisphere function, a left CLEM should accompany the performance of such tasks. When, instead, a stare is the accompaniment, other alternatives must be considered. Firstly, a reduction of visual input may be unnecessary when visualising. This is

certainly counterintuitive if not implausible, especially
when VQs, which presumably involve little, if any, visual
processing, are frequently accompanied by horizontal CLEMs.
However, if the gating out of visual input is unnecessary
while processing SQs, then somehow the model must account for
the apparently selective gating of visual information when
processing VQs. Another alternative is that both hemispheres
are equally involved and are competing for control of the
eyes, each attempting to produce a contralateral movement.
Such a situation can only arise if both hemispheres are
engaged in internal visual-spatial processing, but this is
contrary to the presumed cerebral functioning. Hence, either
visual-spatial processing is carried out jointly by the two
hemispheres, or, the associated CLEM (stare or otherwise) is
unrelated to hemisphere engagement. Both alternatives are
contrary to the assumptions of the model.

Suppose the model to be modified to allow symmetrical
engagement of the two hemispheres when functioning in a
visual-spatial capacity. Not only would it become a simple
gating model for visual-spatial tasks but for all other tasks
also. This is because lateralization of other functions
would have to be disallowed to avoid specifying exceptions on
the basis of observed CLEM/task associations. Making such
exceptions leads to a confused logic whereby the exceptions
to functional laterality are specified in order to explain an
observed CLEM/function association that is then used to
provide evidence for the presumed functional lateralization.

Clearly, although CLEMs may serve to minimize external distraction, the hemispheric component of the model is untenable. The model therefore reverts to a stimulus gating model, the only advance on the earlier Rodin and Singer (1976) version being that CLEMs become an individually learned characteristic.

The third model to be developed to account for CLEMs followed directly from Bakan's (1969) speculative linking of cerebral laterality with eye movements. As a consequence, Kinsbourne (1972) predicted a correlation between question content and eye movements and provided evidence supporting the prediction. He then used his 1970 laterality model of attentional gradient to account for the observed correlations. This model is based on the fact that in subhuman species, the cerebral hemispheres act symmetrically, but differ in that the stimuli that they respond to are derived from their respective contralateral hemispaces, that is, the external surroundings to the left and right of the midline (Gordon & Sperry, 1969, cited in Kinsbourne, 1970). Hence, as a natural outcome, preparatory activation within a hemisphere coincides with attending towards the contralateral hemispace. In humans, this effect is augmented by asymmetric distribution of cognitive functions, especially verbal behaviour. This means that when engaged in a particular cognitive activity primarily activating one or the other cerebral hemisphere, the engaged hemisphere will also attend simultaneously to input from the contralateral hemispace.

Two complementary predictions are generated from the model.
(1) If a cognitive set appropriate to one hemisphere is
adopted, attention is demonstrably biased toward the opposite
side. (2) If attention is constrained to one side, the
cognitive processes proper to the opposite hemisphere are
favoured (Kinsbourne, 1970).

In its application to CLEM studies the Kinsbourne model
invokes the overflow of localised arousal into nearby
"functional centres" to account for the regularities found in
CLEM studies. In his original statement of how this model
could account for the observed correlations, Kinsbourne
(1972) wrote:

> "The cerebrum is a highly linked system, and only
> a few synapses separate any two cortical neurons.
> This makes the cerebrum vulnerable to
> interference between two concurrent operations,
> particularly when both are programmed by the same
> cerebral hemisphere. Thus when subjects await a
> verbal stimulus and must also look centrally the
> verbal activation overflows into the left sided
> orientation centre, driving attentional balance
> off centre and to the right...When the two
> hemispheres are equally active, orientation of
> the subject should be centred on the medial
> plane. When one hemisphere is primarily
> involved, head and eyes should turn to the
> opposite side. These movements should be
> secondary to the central activity rather than in
> direct response to external stimulation." (p.
> 539).

Later, Kinsbourne and Hicks (1978) elaborated "overflow" and
"functional centres" into "functional distance". Functional
distance is the degree to which two or more functioning
centres are linked or otherwise associated in the brain.
Their statement of this more recent development is:

"We now apply the concept of functional dist-
ance to the effect of selective activation of
balance between the ipsilateral and contralat-
eral orienting control centres. The activation
of the hemisphere primarily responsible for
whatever is the existing cognitive state leads
to some spread of activity into the homolateral
control centre and therefore tips the balance
of orienting tendencies such that the vector
resultant orientation is swung contralateral to
the more active hemisphere. Any spread of acti-
vation to the opposing centre on the other side
of the brain is naturally more limited because
of the functionally greater distance to be tra-
versed and therefore insufficient to off-set
this asymmetric effect. It follows that when a
hemispherically specialised cognitive set is
adopted, and the direction of orientation of
the person not specified by the experimenter,
there will be observable orienting biases
contralateral to the active hemisphere. (sic)"
(p. 355).

That Kinsbourne's models have guided the bulk of CLEM

research since 1972 can be seen in the emphasis that

investigators have placed upon the presumed link between

CLEMs and lateralization of cerebral functions. In fact,

other than those studies dealing with ocular motility or the

"gating" models, all investigations linking CLEMs and

specific cognitive activities have invoked Kinsbourne's

laterality model to some degree. Thus, there are almost 80

relevant studies (De Gennaro & Violani, 1988), ample evidence

to evaluate the model.

De Gennaro and Violani (1988) reviewed 79 studies and found

that while 37 supported Kinsbourne's model in finding that

right CLEMs accompanied VQs, only six found left CLEMs in

response to SQs while 36 found no significant differences;

the evidence for the model is therefore decidedly equivocal.

However, even if all of the available evidence did support

this model, it can only account for the horizontal component of CLEMs. Although Kinsbourne (1972) explained stares and vertical movements in terms of balanced cerebral activity, no mechanism has been provided to convert equal hemispheric activation into vertical movements. Also, balanced activity does not provide an adequate accounting of stares. If, while processing an SQ, both hemispheres are equally active, momentary fluctuations in the balance would be expected to produce concurrent fluctuations in eye position at a rate proportionate to cerebral activity over and above that due to the resting base rate. However, the ocular motility studies have shown that for SQs, motility actually decreases rather than increases (Ehrlichman & Barrett, 1983a).

Furthermore, the predominance of stares and upward movements, rather than lateral CLEMs, in response to SQs suggests that visualisation and other supposed right hemispheric functions are more evenly shared between the hemispheres than is presumed by the model. This model therefore seems to apply only to the horizontal component of CLEMs, and possibly only to those CLEMs associated with VQs.

Even this restricted domain is of doubtful utility since "functional distance" can be used to account for just about any behaviour. A simple statement of Kinsbourne's idea of "functional distance" is that neural activity in centre A can, as an incidental byproduct, induce activity in centre B

by virtue of and in proportion to their functional
separation.

The original overflow model is not a neurological one
(Ehrlichman & Weinberger, 1978) and nor is the more recent
functional distance model. There is no logical requirement
for one centre to be an oculomotor one or even for the two
centres to be located in the same cerebral hemisphere. Nor
is there any requirement for the activity to be facilitative
since an inhibiting activity seems to be equally legitimate.
Moreover, activity between the centres need not be in only
one direction; two-way or even mutual activity could occur.
Finally, restricting the activity to just two centres is
unnecessary; one centre can activate two or more centres,
possibly even a network of secondary centres. Current
evidence does not support the model. For instance, in a
psychophysiological study, Davidson, Chapman, Chapman, and
Henriques (1990) failed to find any correlation between
frontal EEG records and task related asymmetries after eye
movement artefacts had been removed. Had there been overflow
from the engaged hemisphere into the frontal eye fields, then
one would have expected at least a low correlation between
recordings. The functional distance model, in either its
original or modified form, seems to be something of a "catch
all".

Furthermore, the semicircular logic that attends the
hemispheric gating model applies to this model also. That

is, the direction of eye movements is explained in terms of presumed hemispheric activity induced by the processing of a specific class of stimuli that is presumed to activate the cerebral hemisphere that initiates the eye movement.

Kinsbourne's cerebral laterality model of CLEMs must also be considered in the wider context of his 1970 attention gradient model of asymmetric cerebral functioning. The attentional gradient model has been extensively tested using a wide range of visual, auditory and haptic stimuli, the results being mainly contrary to the model (Bradshaw & Nettleton, 1983). These studies, covering divided field, dichotic and dihaptic stimulus presentation techniques, used a variety of methods to manipulate the attention gradient. The methods included blocking the stimuli in one hemispace versus randomly distributing them over both spaces, blocked or random stimulus categories such as verbal stimuli compared to geometric stimuli, and priming one hemisphere with a concurrent second task such as verbal memory load or finger tapping. In a review of the evidence, Bradshaw and Nettleton mentioned 10 studies that supported the model and 17 that did not. They concluded that while there was some evidence to support the notion of attentional effects in the asymmetries of functional laterality, the model requires substantial modification.

It can be seen, then, that no matter whether one regards Kinsbourne's cerebral laterality account of CLEMs as being a

stand alone model or as being a special case of his attentional gradient model, the evidence relating to it is decidedly equivocal.

All of the models purporting to account for the apparent link between reflective thought and eye movements can be criticised on methodological grounds. Additionally, Rosenberg's (1979) hemispheric gating model and Kinsbourne's lateral attention models can be faulted at a more fundamental level. Both models presuppose that the notion of lateralized hemispheric functioning is valid; if this notion is incorrect then the models based upon it must also be invalid. This is a crucial point, the importance of which justifies a diversion for a detailed consideration of the issue.

Models of cerebral laterality

The notion that the two cerebral hemispheres have differing functions and relative dominance dates from the middle of the 19th century (Broca, 1865; Dax, 1865, both cited in Allen, 1983). Since then, research in the area has increased to such an extent that Allen noted that papers were appearing at the rate of three or four per week. Not surprisingly, both the number of putatively lateralized functions and the number of models required to account for them is also quite large.

Most papers that contain an important modelling component focus primarily on the model(s) that are immediately related

to the author's viewpoint; local models, as Allen (1983) calls them. For instance, Zaidel (1983) devoted five pages to three models derived from clinical neurology, followed by 39 pages comparing the direct access and callosal relay models derived from split brain studies. Hellige (1987) considered an averaging model, a first home model and two dominance models within a hemispheric interaction framework. Again, Sergent (1982) dealt briefly with the traditional verbal versus visual-spatial dissociation and more recent analytical and holistic (and derivative) models before focusing on her own sensory input model.

Despite the large number of cerebral laterality studies, there have been only a few broad reviews covering the full range of erstwhile laterality models. Given the variety of models, their classification by the various reviewers is somewhat idiosyncratic. Bertelson (1982) divided the models into structural and dynamic ones. Structural models, which depend upon the fixed properties of the efferent pathways to the two hemispheres, are of two basic types. Either a particular function is strictly located in one hemisphere, or the two hemispheres differ in the relative efficiency with which they carry out the same function. The alternative dynamic models also are of two basic types. Either functional localization models, where the right hemisphere is actively inhibited by the left hemisphere for certain functions, or attentional models in which the balance of activation is controlled by a form of mutual inhibition.

Bertelson thus recognised four distinct models that describe the mechanisms of cerebral lateralization without invoking the *nature* of the lateral specialization. This he treated as an independent topic.

Cohen (1982) made an identical initial classification but then further subdivided the structural models in terms of the nature of the various functional specialities. She specified the nature of the specialities as the type of stimulus, type of processing, and stage of processing thereby producing six structural models.

Hardyck (1983) adopted a different classification in which the anatomical locus (structural) models were noted without any attempt at subdivision, while models based solely on the nature of the hemispheric specialization were also accepted, albeit critically, as legitimate variants of the structural pathways models. The dynamic models were also considered to be structural variants. Hardyck then introduced a new classification of *similarity* models. These treat the two hemispheres as duplicate processors of limited capacity and few differences. Two such models were considered, the first being Sergent's (1982) visual-spatial frequency model in which hemispheric asymmetries are a function of the stimulus properties. The second was the dual processor model proposed by Friedman and Polson (1981). In this model the two hemispheres are considered to be independent pools of resources, each having its own unique composition and

efficiencies, and being capable of performing any task
required of it.

The most comprehensive treatment of cerebral laterality
models is due to Allen (1983) who, in a wide ranging review,
made a primary distinction between unilateral and bilateral
models. In unilateral models cerebral functions are strictly
localized to one or the other hemisphere; models that specify
the nature of the functions, such as verbal-visual, analytic-
holistic, etc., are subsumed under the unilateral category.

Bilateral models, where more or less hemispheric interaction
is presumed, are divided into four categories: cooperative
interaction models, negative interaction models, parallel
models and allocation models with several examples of each
type being examined.

Allen (1983) considered two forms of cooperative interaction
models; in one, both hemispheres perform the same function
with their final output being combined into a vector sum. In
the second, the two hemispheres simultaneously perform
different task components which are then combined to produce
the final output. Similarly, two basic negative interaction
models were described; unidirectional inhibition of one
hemisphere by the other, and mutual inhibition by both.
Allen pointed out that unidirectional inhibition would
maximise hemispheric differences which would be valuable
where bilateral rivalry might occur, such as in voice

control.   Conversely, mutual inhibition minimises hemispheric differences which would be essential for symmetrical activities such as walking.

Parallel models require that the two hemispheres operate both simultaneously and independently. Allen (1983) again distinguished two basic types, one where both hemispheres perform the same function and the other where each performs qualitatively different functions or subcomponent functions. Such models appear to have been invoked mainly for the early stages of processing and have little to say about how the two outputs are finally combined.

The final class of bilateral models hypothesize that processing is allocated to one or the other hemisphere, but not both at once.   Three broad classes can be recognised. Input models where allocation occurs early in the process, output models where the final processing stages are allocated to one hemisphere, and finally, switching models where the processing is switched back and forth between the hemispheres. Allen (1983) describes several examples of each class, a major distinguishing feature being the method proposed for the actual allocation to one or the other hemisphere. For instance, priming by either the stimulus or the task requirements, directed attention and voluntary strategy selection have all been proposed. For present purposes, only a few features of these examples need be remarked upon. It can be noted that if a subject's

performance approximates to an output model, the apparent laterality that is observed may be determined by the last hemisphere to be involved since this may well be the response selection and programming steps. Furthermore, switching models have problems with processing requirements. For instance, suppose one section of the process must be carried out using sequential steps and that this is done by one hemisphere, while another section of comparable processing requirements is completed by the other hemisphere using parallel processing. It is easy to see that the processing time required by the first hemisphere may contribute disproportionately to reaction time (RT) measures compared to the other hemisphere even though resource demands are similar in each case.

From this necessarily brief overview of cerebral laterality models it appears that the ubiquitous dichotomisation of cerebral functions cannot be regarded as the only, or even most likely, form of cerebral laterality. Furthermore, there is a plethora of laterality models that purport to account for what is supposedly a coherent phenomenon. This in turn may lead laterality research into a range of conflicting conclusions depending upon which model is used (implicitly or explicitly) to interpret the data.

With functional laterality presuppositions being at least controversial it is contended here that the notion of cerebral hemisphere dichotomies has, in fact, helped to lead

CLEM studies into a *cul de sac*. It has done this directly via the laterality assumptions of Kinsbourne's models which have overwhelmingly dominated the area, and indirectly by interacting with the methodology, which itself is rife with ambiguity and inconsistencies.

Methodological and conceptual problems

Reduced to its essentials, a CLEM experiment consists of asking the subject a set of questions, recording the eye movements that occur in the interval between the asking and the responding, then correlating the movements with the question content. Unfortunately this attractive simplicity conceals a host of methodological and conceptual problems.

Strategic problems

The CLEM literature that has grown up over the past 25 or so years can be characterised by one word: uncoordinated. Hiscock (1986) admirably summarised the situation thus:

> "(C)LEM studies accumulated rather chaotically. The literature is a collection of isolated reports with very few series of experiments performed stepwise *and no careful parametric studies*. [emphasis added]. Consequently, one experiment typically differs from another in various ways and, because experiments are not comparable, it is difficult to pinpoint the reason for discrepant outcomes." (p. 276).

This statement remains strictly applicable today in 1995.

Defining CLEMs

Problems arise as soon as any attempt is made to define
and/or identify CLEMs. There are three interrelated sources
of difficulty. What direction and magnitude of movement, if
any, constitutes a CLEM? What time interval must it occupy?
If multiple movements occur, which, if any, shall be
disregarded? Are only horizontal movements to be classified
as CLEMs or should vertical and diagonal movements also be
included? If so, is a diagonal CLEM the resultant of
simultaneous vertical and lateral movements or is it a CLEM
in its own right? These questions have been treated in
different ways by various authors.

For example, non-horizontal CLEMs have been ignored (Borod et
al., 1988; Deijen et al., 1986; Schwartz et al., 1975),
forced into a laterality framework (Berg & Harris, 1980;
Saring & Cramon, 1980), decomposed into vertical and
horizontal components (De Gennaro & Violani, 1988; Ehrlichman
et al., 1974; Galin & Ornstein, 1972), or treated as a
separate phenomenon (Kinsbourne, 1972) The ocular motility
studies referred to earlier focused on stares as the
phenomenon of interest. With stares frequently accompanying
the processing of SQs it appears that a CLEM can be a CLEM
when it does not occur. So far, then, there is no general
consensus on what constitutes a CLEM.

Even if all eye movements and stares are considered to be
CLEMs there is still the problem of distinguishing one from

another. Subjects are often told to fixate during the
question period or the experimenter "catches their eye".
Given an initial centralization of the eyes, how much
movement is necessary before fixation becomes a CLEM? Kocel
et al. (1972) accepted any observable movement, Kinsbourne
(1972) used five degrees of movement, Deijen et al. (1986) 10
degrees, while Rodin and Singer (1976) required "full eye
movements". Conversely, how long may the subject maintain an
initial fixation before a lack of movement should be
classified as a stare? Furthermore, instructions to fixate
bring their own problems; they may interfere with spontaneous
eye movements and at the very least will contaminate the
experiment by making subjects aware of their eyes.

Making the complementary distinction, when does a CLEM become
a stare, introduces ambiguity to the problem. If, instead of
centrally fixating, the subject is looking left, say, during
question time and then looks straight ahead, is this a stare
or a rightward CLEM? Furthermore, if time intervals are
considered, is it a right CLEM *followed* by a stare and are
they related to the same or different stages of the task
requirements? Only one study has been found where a CLEM was
accepted from a non-central starting position (Saring &
Cramon, 1980).

The interplay of eye movement, direction and time interval
make distinctions even more ambiguous when the eyes move
during questioning, processing and answering. Where

movements occur during all three periods, the CLEM of
supposed interest is sandwiched between two other movements
making its identification and relationship to particular
processing stages very uncertain. If one of the adjacent
movements is in the same direction as the target CLEM,
identification is all but impossible.

The chaos of CLEM research has resulted in only a few
attempts to specify the most appropriate time interval for
detecting a CLEM. These studies collectively provide a good
example of the disorganised nature of the entire field, both
between and *within* studies.

Saring and Cramon (1980) distinguished between questioning,
reflective and answering periods. They also recorded the
first CLEM in each period and the directional frequency of
all CLEMs within each period including stares but excluding
vertical movements. Raine et al. (1988) used the same three
time intervals but recorded the cumulative time within each
period that was spent in making left or right CLEMs. Stares
and vertical movements were ignored. Falcone and Loder
(1984) recorded the gaze direction at the end of the question
and then the respective total times spent in making left,
right, up and down movements over the combined reflective and
answering periods. Stares, however, were excluded. Wyler et
al. (1987) were inconsistent in their measures. In one
experiment, after distinguishing among the three time
periods, they recorded the initial CLEM following the

question plus the respective times spent making left or right CLEMs during the question or answering periods. In their second experiment, however, they recorded only the first CLEM in the reflective and answer periods. Stares and vertical movements were ignored.

In addition to the temporal difficulties just described, other sources of artifact in the physical and social environment of the CLEM experiment may also cause problems. For example, the interpersonal distance and position of the experimenter can influence results by biasing the direction of eye movements as can asymmetries in the subject's visual field (Ehrlichman & Weinberger, 1978).

In sum, the unambiguous identification of CLEMs is a major problem that has, as yet, no satisfactory solution.

Stimulus questions

The questions used in CLEM studies and the presuppositions underlying their selection are another source of interpretive difficulties. A number of authors have noted that some questions are more likely to elicit CLEMs than others (Argyle & Cook, 1976; Duke, 1968; Meskin & Singer, 1974). Ehrlichman and Weinberger (1978) summarise the position by noting that questions that call for overlearned material and simple responses seldom give rise to CLEMs, but those requiring more complex processing often do so. This conclusion appears to be plausible but is based on essentially anecdotal evidence.

A systematic investigation of CLEMs and question difficulty has never been carried out. Nor has the possibility of equating a stare to this failure to move the eyes when simple overlearned responses are given ever been mooted. There are, however, a few studies that may be relevant to the issue.

Klinger, Gregoire, and Barta (1973) reported that the performance of high concentration tasks and choice tasks resulted in high ocular motility whereas low concentration tasks and imagining were associated with low ocular motility. May et al. (1990) obtained a systematic decrease in saccadic extent with an increase in the complexity of a counting task. However, Meskin and Singer (1974) reported that CLEM frequency increased as mental search requirements increased. These reports relate more to ocular motility than CLEMs, but unlike the ocular motility results, described earlier (p. 13), these are contradictory and rather confusing.

Ehrlichman and Weinberger (1978) also write that the assumption that CLEM directions reflect hemispheric asymmetry rests upon another yet assumption. Namely, that the question does in fact engage the targeted hemisphere more than the non-targeted one. There is a real danger of circularity here since there is little, if any, independent evidence to support either assumption. Most of the available evidence that relates to these assumptions comes from CLEM studies that are predicated on these very assumptions.

The evidence deriving directly from CLEM studies is often either inconclusive or contradictory. Of the 19 experiments catalogued by Ehrlichman and Weinberger (1978), 10 failed to find any significant difference between SQs and VQs in terms of lateral CLEMs. Furthermore, the same or very similar questions were used in both successful and unsuccessful experiments. For instance, Ehrlichman et al. (1974) obtained differing results using questions from the successful study by Kocel et al. (1972). Again, Weiten and Etaugh (1974) and Gur, Gur, and Harris (1975) used numerical questions with different outcomes. Ehrlichman and Weinberger summarise the position as follows:

> "The main support for the assertion that CLEMs indicate hemispheric asymmetry is that a non-obvious pattern of results has been found in a number of studies in which specially selected questions appear to have differentially affected the direction of eye movements. The primary reason for attributing this pattern to hemispheric asymmetry is that the left and right hemispheres seem to be related to question and response" (p. 1091).

And that:

> "In general, a rough rule of thumb seems to have been that if a question's main emphasis is on verbal meaning or manipulation of words or symbols it is a left hemisphere question; if it involves visualisation or music it is a right hemisphere question" (p. 1084).

Even today, 17 years later, there seems to be only one study where a deliberate attempt was made to avoid the circularities involved in assuming the engagement of a particular cerebral hemisphere. Lefevre et al. (1977) employed a dichotic stimulus presentation in an effort to

ensure that the stimuli did reach primarily the targeted hemisphere. CLEMs were recorded as subjects responded to two classes of stimuli, verbal (digit sets) and non-verbal (environmental sounds). Right CLEMs were significantly associated with both verbal stimuli and a right ear advantage, while left CLEMs were significantly linked to non-verbal stimuli and a left ear advantage. Unfortunately, the dichotic listening paradigm cannot be used as evidence for preferential activation of one cerebral hemisphere over the other. The method requires that stimuli be presented in pairs, one to each ear. This means that each hemisphere receives not less than half of the available information, rendering ambiguous the main processing locus. Furthermore, the auditory system does not decuss, as does the visual system; consequently a lot of ipsilateral input to the cerebral hemispheres occurs (Graham, 1990).

In sum, it is evident that investigators have relied on a form of face validity conforming to generally accepted ideas of hemispheric functioning. That these ideas may not be in accordance with reality can be seen by examining the results of a small number of psychophysiological studies bearing upon the relationship between CLEMs, question type and hemispheric activation.

Psychophysiological studies

Direct evidence that SQs and VQs may selectively activate the cerebral hemispheres has been provided by Ehrlichman and

Weiner (1979). They made electroencephalographic (EEG) recordings of integrated *alpha* amplitudes while subjects solved a series of verbal and spatial problems. A significant task x hemisphere interaction was found with the biggest change in integrated amplitude occurring over the left hemisphere for spatial tasks. Significant main effects for both task and hemisphere were also found. Between- and within-subject correlations were high, with means of 0.88 and 0.75 respectively. The authors considered their results to be good evidence for task-related asymmetries in integrated EEG amplitude. However, this study may have been contaminated by movement artefacts due to the use of pencil and paper and manipulation tasks. Also, no effort was made to control or record concurrent eye movements.

A second EEG study was conducted with subjects carrying out covert verbal and spatial tasks, among others, while lying down with their eyes closed (Ehrlichman & Weiner, 1980). Subjects rated their covert engagement in the tasks and these ratings were correlated with their EEG recordings. Covert verbalisation ratings were systematically related to EEG asymmetry. Also, tasks that could reasonably be classified as primarily involving left or right cerebral hemispheres showed clear differences in EEG asymmetry. However, after partialing out the variance due to the substantial negative correlation between imagery and verbalisation, it was found that imagery made no independent contribution to that asymmetry. Also, semi-partial correlations with ratings of

concentration were very similar to those for verbalisation. Additionally, all semi-partial correlations for verbal, visual and concentration measures were negative. The authors concluded that EEG asymmetries are very sensitive to the presence or absence of verbal processes but indifferent to visual ones, and that an exclusive emphasis on a verbal-visual dichotomy is shortsighted.

The apparent sensitivity of EEG asymmetry to verbal processes would suggest that if EEG potentials index hemispheric activation, then even *incidental* verbal processing will result in asymmetric activation. In short, *listening* to a question will result in asymmetric activation and thus initiate an associated CLEM. Similar reasoning suggests that speaking should also be associated with its own unique CLEM. Both of these effects have been reported by Wyler et al. (1987) who found that their subjects generally made leftwards CLEMs when listening and rightwards while speaking. It has even been suggested that subvocalisation might well have comparable effects (Davidson et al., 1990).

In the two studies just described, no effort was made to match the tasks psychometrically, nor were different electrode placements and references examined. If tasks are not equated for demands and difficulty, asymmetric activation of the cerebral hemispheres may be due to task demands rather than their visual or verbal content. Also, little has been done to determine those electrode placements that give the

most reliable EEG measures, and the reference electrode placement remains a controversial issue (Davidson et al., 1990).

Some of these methodological weaknesses were examined by Davidson et al. (1990) using psychometrically matched tasks of dot localisation (visual) and word matching (verbal). Left and right EEG recordings were taken from frontal, central and parietal sites using both vertex and averaged ears references. Recordings were made in the *alpha, beta, delta* and *theta* frequency bands and all movement artefacts were removed prior to analysis.

Three of their results are of immediate concern. Firstly, the spectral power of the electrical potentials from the hemisphere that was putatively engaged was always reduced. This finding is consistent with the results of Ehrlichman and Weiner (1980). Secondly, it is relative suppression of power that is associated with task performance. This implies that both hemispheres are activated rather than only one of them. And thirdly, central and parietal asymmetry was more highly correlated with task performance than was frontal asymmetry. In fact, *no* frontal correlations approached significance. This is a most important point, since, if the frontal eye fields are involved in the production of CLEMs associated with lateralized cognitive processing, then asymmetric activation of the frontal cortical regions should correlate with task-related EEGs.

Taken together, the findings of Erhlichman and Weiner (1979, 1980) and of Davidson et al. (1990) provide evidence for the asymmetric activation of the left cerebral hemisphere when engaged in verbal tasks. Visual tasks, on the other hand, appear to result in a more symmetric activation of the two hemispheres, rather than a predominately right hemisphere activation as is usually assumed.

There are, however, reservations to be made regarding this evidence. Tasks were presented visually by both Ehrlichman and Weiner (1979) and Davidson et al. (1990), whereas in CLEM studies spoken questions are used. The equivalence of verbal and visual presentations has not, as yet, been investigated. In the Ehrlichman and Weiner (1980) report, the authors relied upon their subjects' assertions that they had in fact engaged in the assigned task. Also, eye closure merely prevented external visual stimulation; it did not necessarily prevent contamination with covert eye movements.

In two of these psychophysiological studies, efforts were made to avoid contaminating the EEG measures with eye movement artefacts. This prevented an investigation of any relationships between CLEMs and selective hemispheric activation, especially temporal ones. Only two studies have been found that address the putative relationship between CLEMs and hemispheric activation as indexed by EEG recordings.

In the first of these, Warren and Haueter (1981) measured
lateral *alpha* EEG potentials concurrently with EOG records of
the CLEMs associated with VQs and SQs taken directly from the
CLEM literature. The time intervals used in the analysis
were the two seconds immediately preceding the peak EOG
deflection and the two seconds following a one second
interval after the peak EOG deflection. The only significant
result was an interaction between the CLEM direction and the
time interval. This was due to an increase in *alpha* EEG
asymmetry from pre- to post-CLEM when a rightwards eye
movement was made. The authors concluded that task related
alpha EEG asymmetry may depend upon concurrent eye movements,
the effect of such movements also being asymmetric.

In a similar experiment, Neubauer, Schulter, and
Pfurtscheller (1988) used synonyms and orienting tasks for
their VQs and SQs. An interesting feature of their stimuli
was that only one word was required for both presentation and
response. That is, for VQs, subjects were required to
provide a synonym to a one word stimulus, while for SQs, they
named the direction of landmarks relative to a fixed
reference point. Requiring single words only for both task
presentation and responses would have reduced the possibility
of contaminating task performance with extraneous language
processing. EEG power measures were taken from several
bilateral scalp sites concurrently with EOG records of
horizontal CLEMs, all measures spanning several time
intervals. Subjects fixated centrally while the stimuli were

presented. The EOG records were used to classify the subjects into left, right or bidirectional eye movers.

There were no significant interactions involving CLEM direction, cerebral hemisphere or task for any of the earlier time intervals up to and including the first CLEM. Also, most importantly, there were no significant effects at all involving bidirectionals or the EEG measures taken from either the frontal regions or concurrently with SQs. Significant results were restricted to the one second interval *before* the responses made to VQs by left and right movers. Left movers showed a significant right hemisphere activation in the temporal-parietal regions for synonyms immediately prior to their responses. Right movers showed a (nonsignificant) trend in the opposite direction. Similar but nonsignificant trends were found for central EEG recordings for both groups. The authors concluded that a contralateral CLEM might well be a necessary precursor to task related asymmetric cerebral activation.

One final psychophysiological study is relevant to this discussion. Biggins, Turetsky, and Fein (1990) used EEG recordings in conjunction with a divided field choice RT task to investigate possible loci for imagery. They found no evidence for hemispheric asymmetries for either visual perceptual processing or imagery.

The results from these six psychophysiological studies display a number of important consistencies. Firstly, the five that used verbal tasks all found similar task-related EEG asymmetries. Secondly, in four of these five studies, the asymmetries were entirely attributable to the activation of the left hemisphere when using verbal material. Conversely, in five out of the six studies visual-spatial material resulted in symmetrical activation of the cerebral hemispheres. Thirdly, the two studies that recorded EEG power from several positions found no evidence for asymmetric activation of the frontal cortex. Finally, both of the studies recording observations over several time intervals reported that asymmetric activation *followed* the first CLEM. Thus, it can be noted that while there is independent evidence that a VQ can result in more activation of the left cerebral hemisphere compared to the right one, an SQ is more likely to produce symmetrical activation. Therefore, investigators' reliance on the presumed face validity of question content is only partially justified. Unfortunately, even partial justification is made suspect by the possibility of alternative processing strategies.

Cognitive strategies and laterality

The processing strategies used by a particular subject provide a further source of uncertainty in relating CLEMs to cognitive processes. Kinsbourne (1972) notes that the tasks used in CLEM experiments can often be solved in more than one way. By way of illustration, Norman (1976) lists several

strategies that have been used as memory aids; these include visualisation, rhymes and word associations. Despite this, only one CLEM study has made a systematic attempt to control subjects' processing strategies (Lemmpert & Kinsbourne, 1982). This leaves open the possibility that different processing strategies may have confounded the outcome of many studies.

Even if all subjects use the same processing strategy, the strategy may contain several different stages, each requiring more or less input from the two cerebral hemispheres. For instance, a visual classification task may require extensive visual processing prior to a final verbal classification step. The evidence from the psychophysiological studies discussed earlier suggests that while the vast bulk of the processing, being visual, is symmetrically distributed across the two hemispheres, *any* verbal activity will produce an effective cerebral asymmetry that may disguise the actual processing requirements. Divided VF experiments by Servos and Peters (1990) are directly relevant to this point. Subjects were required to categorize stimuli that contained strong visual depth cues. Reaction times demonstrated a consistent right VF (RVF) advantage and therefore a (presumed) left hemisphere advantage. This may well have been due solely to the superior verbal abilities of the left hemisphere in the final categorisation stage. Bertelson (1982) discusses this potential confound, noting also that many studies have shown that the same stimulus material can

give rise to different laterality patterns depending upon the processing requirements. It therefore seems reasonable to ask whether it has been demonstrated that *any* of the tasks used in CLEM studies are in fact processed mainly by one or the other hemisphere.

The dangers of assuming that one or the other cerebral hemisphere is preferentially engaged when a subject carries out a given task can be illustrated with reference to visual imagery experiments. A frequently used SQ aimed at the right hemisphere is to ask the subject to imagine some object or place, as Kinsbourne (1972) and Gur (1975) did. However, there have been doubts raised about imagery being a right hemisphere function (Ehrlichman & Barrett, 1983b). Evidence for imagery being a left hemisphere function has been found by Farah, Gazzaniga, Holtzman and Kosslyn (1985) from a split brain subject and Farah (1986) from normal subjects. But these studies have been contradicted, firstly by Sergent (1989) who found a right hemisphere advantage using normal subjects, and then by Sergent and Corballis (1990) testing a split brain patient who demonstrated equal imaging ability by the two hemispheres. Finally, Biggins et al.(1990), using EEG recordings in conjunction with a divided field choice RT task to investigate possible loci for imagery, found no evidence for hemispheric imagery asymmetries. The implication is that other presumed hemispheric specialisations may also be doubtful.

In the light of the foregoing methodological and theoretical
analysis, 26 years of CLEM research can be summarised as
follows. Individuals are generally consistent or habitual in
the eye movements that they make when engaged in reflective
thought. Their eye movements appear to be modified by both
the long term and situational properties of their visual
field. Verbal thought tends to be accompanied by horizontal
movements with a rightwards bias while visual thought tends
to be accompanied by fixed stares or upwards movements.
Finally, not even a partially adequate accounting for
reflective eye movements has been offered so far.

It appears that methodological and conceptual problems
coupled with an unwarranted emphasis on lateral eye movements
have inhibited any major advances in CLEM research. By
emphasizing lateral eye movements, potentially valuable
information obtainable from stares and vertical or diagonal
CLEMs has been neglected. By way of illustration and for the
moment disregarding the ocular motility studies, only four
reports have been found where nonlateral CLEMs received the
same prominence as lateral ones (De Genarro & Violani, 1988;
Ehrlichman et al., 1974; Galin & Ornstein, 1972; Kinsbourne,
1972). All other studies have focused almost exclusively on
lateral CLEMs, even to the extent of selecting out those
subjects who produced mostly nonlateral CLEMs (e.g., Borod et
al., 1988; Walker, Wade, & Waldeman, 1982). Where such
subjects were retained, little attention was paid
subsequently to them, or a strained classification was used

to incorporate them into a laterality framework (e.g., Gur, 1975). Due to this bias, stares, upwards and horizontal CLEMs that accompany SQs have been reported on only three occasions (Deijen et al., 1986; Kinsbourne, 1972; MacDonald & Hiscock, 1984). The selective reporting of data together with culling of subjects prevents one knowing the extent to which stares and/or upwards CLEMs accompany SQs. Such bias has discouraged careful parametric studies and may well have prevented the development of more valid models. In view of the experimental difficulties and theoretical shortcomings outlined above it is apparent that a fresh approach to CLEM research is needed.

Reverse CLEMs: a different approach

As a first step in developing a new perspective on a possible relationship between CLEMs and reflective thought, it can be noted that certain CLEMs discriminate between SQs and VQs at better than chance levels, substantially so in some cases. There are at least two reasons for this. Firstly, CLEMs may be regular by-products of cognitive processing that can serve as diagnostic indicators of those processes. This is where CLEM research began. The second suggestion is that eye movements may be functional accessories to certain cognitive processes. Two psychophysiological studies have shown that eye movements can precede asymmetric cerebral activation. This fact prompted the suggestion that eye movements might be a prerequisite for asymmetric activation (Neubauer et al.,

1988; Warren & Haeuter, 1981). Also, Rosenberg (1980) showed that a wide range of SQs, VQs and combined tasks selectively interfered with ongoing optokinetic eye movements. Taken together, these facts suggest that there might well be a reciprocal relationship between reflective eye movements and cognitive activity. If this were so, then deliberately gazing in one particular direction (a reverse CLEM), would be expected selectively to affect that activity.

Kinsbourne (1973, 1975; Kinsbourne & Hicks, 1978) has repeatedly made similar predictions, his most recent statement being:

> "...the logical prediction that orienting in one
> direction should favour the immediately
> subsequent specialised cognitive processing of
> the hemisphere that programmed the orienting,
> rather than of the alternative hemisphere"
> (Kinsbourne & Hicks, 1978, p. 356).

In other words, if the subject looks right, for example, then performance when answering a VQ will be enhanced compared to looking elsewhere. In terms of both Kinsbourne's (1970) attentional gradient model and (1978) functional distance model this will occur because the left frontal eye fields, being responsible for the contralateral eye movement, will be activated. This activation will overflow into adjacent areas of the left cerebral hemisphere thereby priming or otherwise facilitating its functioning. The right hemisphere, however, will not be so facilitated; hence, a left hemisphere advantage will be observed.

Several studies, some of which were based on Kinsbourne's predictions, provide support, both direct and indirect, for the idea that gaze position (GP) may affect task performance. In most cases the effects were concordant with Kinsbourne's predictions. Unfortunately, however, methodological faults restrict the conclusions that can be drawn from most of these studies.

In three experiments, Hines and Martindale (1974) used goggles with partially covered lenses to direct subjects' gaze sideways while tests of creativity, spatial ability, and abstraction were administered. On five creativity tests, left looking males performed better than right looking males, and on two abstraction tests the right looking group performed best. The same tests administered to female groups resulted in a uniform right looking advantage. Overall, only two out of nine comparisons were significant (males on a creativity test and on a spatial test). The fact that stronger effects were not found may have been due to methodological weaknesses. Partially covered lenses would have forced the subjects to look away from their midlines, but to complete a pencil and paper test, they would almost certainly have tilted their heads in the opposite direction to maintain a comfortable writing posture. Both Kinsbourne (1972) and Lemmpert and Kinsbourne (1982) consider head and eye turning as being equivalent; consequently, in Hines and Martindale's studies it is likely that the two were confounded, and with opposed effects. Furthermore, eye movements during

reflective thought were uncontrolled and the entire experiment may have been contaminated by the head being bowed into a writing position.

Gross, Franko, and Lewin (1978) carried out an intriguing study in which subjects were asked to identify the odd word out of a set of three. Reasoning that the recognition of semantic differences is a left hemisphere function and that rhyming differences would be mediated by the right hemisphere, sets of mixed homonyms and synonyms were used. An example is: WATCH, CLOCK, BLOCK. The dependent measure was the number of rhyming choices made when the subject's eyes were directed to the left or right as required by the experimenter. A significant increase in rhyming choices was made by right handed subjects looking left compared to looking right. Unfortunately, this experiment was also poorly controlled. Subjects were simply told to gaze left or right. Whether to turn their eyes, or head, or both was not indicated, and nor was the angle of gaze. Worse still, because the experimenter sat behind the subjects, there was no monitoring of the gaze for direction, extent or duration. Furthermore, there is evidence that the right hemisphere is *unable* to recognize rhymes (Levy & Trevarthen, 1977, cited in Bradshaw & Nettleton, 1983); so the assumptions underlying the choice of task may be false.

The third study was made by La Torre and La Torre (1981) who used items taken from the WISC with 10 year old children as

subjects. They were asked to look at positions on the surface of a table set between subject and experimenter. The positions were either directly in front of the subject or 45 degrees to the left or right. The only significant effect found was a decreased performance on spatial items when looking right compared to looking straight ahead. This is consistent with Kinsbourne's models in that instead of a contralateral facilitation, an ipsilateral decrement was obtained. In this experiment, the nominated gaze directions would have been contaminated by the requirement to look downwards onto the top of a desk.

Casey (1981) used visual presentation of stimuli with subjects looking 20 degrees to the left or right. Stimuli, exposed for 200 msec, were presumed selectively to involve the functions of the two cerebral hemispheres. For the left hemisphere task, or VQ analogue (VQA), subjects were required to decide whether or not an upper case letter and a lower case one represented the same letter. The two letters appeared together at the designated fixation point. For the presumed right hemisphere task, or SQ analogue (SQA), the letters were replaced by two squares enclosing dots. A same-different choice was required. RTs for the SQA were significantly faster when the subjects looked left than when they looked right. No effect was found for the VQA. The clarity of these results was possibly impaired by the VQA and SQA trials being randomly intermixed, and the fact that some trials were cued and others uncued with respect to their

nature. There is some evidence that random interleaving of conditions may attenuate experimental effects (Ragot & Lesevre, 1986). At the same time, because foveal presentation provides both cerebral hemispheres with the relevant information, nothing can be said about asymmetrical activation and task performance.

Brief visual presentation of high and low imagery paired associate words designed to engage right and left hemispheres respectively was used by Onken and Stern (1981). The stimulus word of each pair appeared at a central fixation point while the associated word appeared to the left or right of the stimulus forcing the subject to attend to left or right of fixation. Cued recall was assessed using a written test. No effects of lateral eye movement on recall were found, which is hardly surprising considering the poor experimental control. Siting the target word to the left or right of the centrally positioned stimulus word was supposed to force the subjects to attend to the right or left, but the authors note that the two words could be read without eye movements. With the target word being presented adjacent to the central stimulus word, this would have produced divided field conditions of unknown and variable retinal eccentricity. Thus, contrary to the authors' claim, this experiment probably had little to do with reverse CLEMs.

Walker et al. (1982) adopted a more conventional method by asking SQs and VQs while their subjects fixated left, right

or centre, with response latency as the dependent measure. They also included a normal CLEM condition. By including central fixation they were able to show that VQs were significantly facilitated by right looking compared to the other two positions but that SQs were significantly inhibited by right (ipsilateral) looking. These results partially supported Kinsbourne's models. This report is a good example of the extent to which Kinsbourne's model has impaired CLEM research. Walker et al. used the normal CLEM condition to remove the bidirectional or non-movers prior to analyzing the reverse CLEM results. Had they correlated all normal CLEMs with all reverse CLEMs they might well have answered their own query regarding the possible instrumental value of CLEMs.

Face recognition and word recognition were used by Tressoldi (1987) as SQAs and VQAs when he investigated the effect of GP on task performance. Tachistoscopic presentation was simulated using either a slide projector or a computer monitor. In the first of three experiments subjects were required to discriminate between words and pronounceable nonwords with reaction time as the dependent measure. Four groups were used: men, women, boys and girls. The relevant significant results were that girls made fewer errors when looking left than looking right, men and boys made faster responses to all stimuli when looking right compared to looking left while women made faster responses to non-words when looking left. This experiment was repeated using only

men, but with the addition of the central eye position. The effect of left or right GP was the same as in the earlier experiment. However, the inclusion of the central GP revealed that the difference between the two hemispaces was due to retardation in the left hemispace compared to the central position, rather than facilitation in the right hemispace. In the third experiment, face recognition was used as an SQA with adults as subjects. For both sexes, RTs were significantly faster in right hemispace for known faces and in left hemispace for unknown faces. These results cannot be interpreted in terms of cerebral hemisphere activation because with foveal presentation both hemispheres would have been engaged.

In an unusual experiment, subjects' perceptions of their own heartbeats were investigated when fixating 30 degrees left or right of centre (Weisz, Balazs, Lang, & Adam,1990). Subjects who habitually gave either left or right CLEMs had more accurate perceptions when looking left compared to looking right. No such effect was found for those subjects who were inconsistent in the direction of their CLEMs. As the authors note, the experiment required that subjects engage in time perception and selective attention, both tasks being potential confounds. Also, they suggest that the innervation of the heart may differ between the two cerebral hemispheres and that this may interact with directional attending.

A report taken from the stimulus-response (S-R) compatibility literature is relevant here. Bowers, Heilman, and Van Den Able (1981) used a divided VF and simple RT paradigm with a go-no go response to investigate hemispace-hemifield compatibility effects. Stimulus lights appeared to left or right of fixation when the eyes were turned 30 degrees to left or right of the body midline. A significant interaction between hemispace and visual hemifield was found. Compared to the body midline, a right GP slowed the RTs for both VFs by about 18 msec. On the other hand, a left GP slowed RVF RTs by 26 msec but had no significant effect on RTs for the left VF (LVF). This effect disappeared with practice. Although the results demonstrated a link between GP and performance, interpreting them in terms of asymmetrical cerebral activation is difficult because within an experimental session, all trials were presented in the one VF so that biased attending to one VF would have occurred. Also, because fixation was not controlled surreptitious eye movements may have contaminated the results by interfering with retinal eccentricity.

Only two studies are known where GPs on the vertical midline have been investigated. In the first of these, Hiscock, Hampson, Wong and Kinsbourne (1985) employed a dichotic listening task while subjects made either a 30 degree horizontal eye movement to left or right or 15 degree upward movement, returning their eyes to the central position before responding. Two experiments, one using consonant-vowel

syllables the other using musical stimuli, were carried out.
Musical localisation was significantly better when ear and
hemispace were congruent than when they were incongruent but
identification was significantly better when the eyes were
moved vertically compared to horizontally. Verbal stimuli
produced no significant effects. Also investigated were the
effects of induced OKN on auditory (verbal) processing, an
experiment that was derived from Rosenberg (1980) who
investigated the effect of cognition on OKN. Eye movements
had no effect on right ear performance but significantly
affected left ear performance. Compared to a central rest
position, right to left nystagmus impaired recall accuracy
while left to right nystagmus enhanced it. The authors
attributed their failure to obtain definitive results from
the first two experiments to their randomising eye movement
directions instead of blocking them. Another possible reason
for the ambiguous results was that the eye movement away from
centre for each stimulus presentation was followed
immediately by a return to centre before making the response.
Thus, two opposed movements were confounded with a gaze
direction together with the possible interference due to
verbal responding. The use of a dichotic listening task also
means that information was provided to both cerebral
hemispheres (Graham, 1990).

Andreasen (1988) employed a divided field two choice RT
paradigm with vertical, horizontal, central and diagonal eye
positions. A significant effect of vertical GP was found,

mostly due to slower RTs when looking downwards. No VF differences were associated with vertical GPs. A significant horizontal right to left improvement in performance was found for the LVF and a similar but nonsignificant trend for the RVF. No support was found for Kinsbourne's (1972) model. Clarity of the results was impaired by a complex three-way interaction. This was attributed to a combination of S-R compatibility and individual variability. The methodology was flawed by having the angles in the vertical plane blocked while the angles in the horizontal plane were randomised across trials. Also, eye fixation at the beginning of each trial was uncontrolled.

None of the preceding studies appeared to use proper head restraints, and chin rests were used in only a few cases so that covert or minimal head turn may have occurred. This is a potentially important point because Kinsbourne (1972, 1975; Lemmpert & Kinsbourne, 1982) appears to regard head and eye turning as equivalent. This can be seen in two studies which, he claims, provide support for the laterality model as applied to the eye movement facilitation of task performance. In one experiment (Kinsbourne, 1975) a paired associate learning task was used. The response measure was the time taken to turn the head, on cue, in one direction or the other, locate a visually displayed probe and respond verbally. Initially, recall was significantly superior for right GP, but after 32 trials it was replaced by a significant left GP superiority. Kinsbourne interpreted his

results as indicating that initially a verbal recall strategy, mediated by the left hemisphere, was used. With practice this became over-learned and was replaced by a right mediated visual recognition strategy.

The second of his studies (Lemmpert & Kinsbourne, 1982) is the only one where a deliberate attempt was made to control the subjects' processing strategies. Subjects learned "noun-verb-noun" sentences using either a verbal rehearsal strategy or a visualisation strategy. They learned the sentences while looking over one shoulder or the other, turning both head and eyes. The only significant effect of gaze direction was in the verbal rehearsal condition where superior learning when looking over the right shoulder was found. Kinsbourne has consistently maintained that "head and eye turning indicates cerebral lateralization", this being the title of his 1972 paper. One can infer that he considers the two types of movement to be equivalent and possibly interchangeable in their effects. However, no evidence has been offered to show that head turning can be equated with eye movements. Even if they can be equated, they were completely confounded in these two studies. Other confounding effects include head movement, visual search and, possibly, fatigue. Regardless of the relevance that head turning has for the effect of eye movements on task performance, the two studies just described provide only dubious support for the laterality model.

However, head turning was used by Boliek, Obrutz and Shaw (1988) to investigate the effect of hemispace orientation during dichotic listening. Although unrelated to CLEMs, the results are relevant to Kinsbourne's claim that both head and eye turn are linked to cognitive processing. Nonsense syllables were presented dichotically with immediate recall while the subject's head was turned 90 degrees to the left or right. Compared to a central control position, left ear performance was unaffected by head turning but right ear advantage increased significantly when the head was turned to the right. Using Kinsbourne's models to interpret this result leads to the conclusion that the effect of contralateral orientation is restricted to left hemisphere facilitation. Because right hemisphere performances were unaffected, Kinsbourne's models are only partially supported.

To summarise, a number of studies have provided support for the idea that controlled GP may affect task performance; the direction of the observed effects has usually been as expected from Kinsbourne's models. However, there were many methodological shortcomings in the studies to which can be added a number of other reservations.

First of all, how comparable are the various tasks that have been used? For example, brief stimulus RT tasks versus questions? Next, not all studies included a central GP. So, were the effects due to a performance increment in one direction or a decrement in the other? Where a central GP

was used the effects varied both across and within studies.
Tressoldi (1987) reported an ipsilateral decrement in
performance for non-words but a steady ipsilateral to
contralateral increment for words. Walker et al. (1982)
found a contralateral increment for VQs but an ipsilateral
decrement for SQs. Bowers et al. (1981) obtained an
ipsilateral decrement for the LVF but both ipsilateral and
contralateral decrements for the RVF. Finally, Andreasen
(1988) obtained ipsilateral and contralateral decrements for
the LVF but a steady increment from contralateral to
ipsilateral gaze positions for the RVF. There appears to be
no systematic pattern to these results. Also, only one study
made an explicit attempt to control the subject's cognitive
strategies, although the RT and latency studies would have
restricted them. At the most, only the divided field studies
can be considered to have evaded the circular arguments
involved in the notion of lateralized cerebral functioning
and the use of SQ and VQ analogues.

In spite of all these criticisms, it seems that GP interacts
with the performance of a wide range of tasks. In fact, when
GP was treated as the independent variable, 13 out of 14
studies reported at least one significant result. Finding
that task performance interacts with GP across such a diverse
range of tasks suggests that adopting this approach will
allow CLEMs to be identified and related to particular
cognitive processes. Any or all CLEMs can be identified at

will and the problem of separating one CLEM from another disappears simply by eliminating other CLEMs.

There are further gains to be made if GP is experimenter controlled, namely, the problems of task content that are associated with the use of questions can be avoided. There is nothing mandatory about questions. Other forms of task presentation are available, but adherence to the early formulations of Bakan (1969), Kinsbourne (1972) and Kocel et al. (1972), plus the attractions of simplicity, have resulted in the almost exclusive use of questions. With the CLEM controlled, the task can be presented in any sensory modality with its content precisely specified. By extending the experimenter's control in this way, subjects can be forced to use only one processing strategy or at least be restricted in their range of choices. There is also the possibility that, by using divided VF methods to ensure that the task is presented selectively to only one cerebral hemisphere, the previously noted circularity involved with questions can be avoided. Also tasks that do not require verbal responses can be used, allowing for a wider range of response measures.

It was earlier suggested that an undue emphasis on functional hemispheric laterality coupled with methodological and conceptual difficulties has hindered CLEM research. The single most potent source of these difficulties is possibly the persistent use of the CLEM as the dependent measure. Not only are the temporal and directional properties of this

measure ambiguous, but its use involves presuppositions that themselves are contentious and unclear. To remedy this situation it has been proposed that by making GP the primary independent variable most, if not all, of the methodological difficulties will be resolved. Furthermore, by presenting stimuli to one or the other VF, the underlying conceptual problems will also be resolved or evaded. Consequently, all of the work reported in this dissertation uses GP and VF as the independent variables to investigate the possible functional relationship between CLEMs and cognitive processes.

Programme overview and hypotheses

The first objective of the programme was a partial replication of Andreasen (1988) using more stringent experimental controls together with a clarification of certain methodological issues. Following this preliminary work, the programme was developed into a series of parametric studies covering a number of related topics. The primary interest lay in testing Kinsbourne's lateral arousal account of CLEMs within the context of his attentional gradient and functional distance models of cerebral laterality, using GP and VF as the independent variables.

With GP as the independent variable, two predictions can be made from Kinsbourne's model. First, if horizontal eye movements are controlled by the contralateral cerebral

hemisphere, contralateral movements will activate that hemisphere. Then, since each cerebral hemisphere will be selectively engaged by unilateral stimulus presentation to the contralateral VF (Sergent, 1983), a horizontal GP x VF interaction should be observed regardless of the task. Specifically, when the eyes are directed to the left of centre (i.e., a left GP) activating the right hemisphere, stimuli presented to the LVF should be processed more effectively than stimuli presented to the RVF due to the activating (priming) effect of the eye movement. A comparable effect should be observed when the eyes are directed to the right of centre. Furthermore, *both* of these effects should be observed for each subject, and, assuming symmetrical magnitudes of effect for each hemisphere, a crossover GP x VF interaction should be found.[2] Secondly, since vertical movements are bilaterally controlled (Bender, 1980), *no* GP x VF interaction should be found when the GP is deviated vertically upward or downward. This prediction arises because if a contralateral movement can activate selectively the controlling cerebral hemisphere, then, since both hemispheres are engaged in the control of vertical movements, both hemispheres should be activated when such vertical movements occur. Therefore, any vertical movements

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[2] The tasks used in this programme were, intuitively, rather simple and thus more likely to be associated with facilitative priming effects rather than the interfering two task effects that occur as a result of more demanding conditions (Moscovitch & Klein, 1980). Therefore, eye movements, being a very simple secondary task, are treated as cerebral priming agents. Consideration of their possible role in dual task performance is more properly left until the general discussion.

will activate both of the hemispheres relative to the central resting position thereby facilitating the performance of either hemisphere (targeted by the associated VF) regardless of the direction of that movement. This facilitation should therefore result in a GP main effect rather than a GP x VF interaction. By using a divided field task and including vertical GPs, Kinsbourne's (1972) model can be subjected to some stringent tests.

A controlled GP methodology is also very relevant when considering the more general models (Kinsbourne, 1970; Kinsbourne & Hicks, 1978). One of the predictions made when the models are applied to CLEMs is that when attention is directed to one hemispace, the functions of the contralateral cerebral hemisphere will be facilitated. For the more usual divided field situation, when attention is constrained to one VF, any VF advantage due to the verbal or visual nature of the stimulus will be reduced compared to the situation where trials are randomly presented to the two VFs. This comes about because when the trials are blocked the subject's ability to predict the VF will activate the contralateral hemisphere. This activation will then override any advantage due to selective activation of the preferred hemisphere by the verbal or visual nature of the stimuli. This prediction has been tested by blocking the stimulus trials, mixing verbal and visual together, within each VF and comparing the results from these trials to those obtained when the trials are randomised between VFs. The results have been equivocal

but tend to disconfirm the prediction. All of the relevant studies reviewed by Bradshaw and Nettleton (1983), used either dichotic or divided field stimulus presentation (thereby confounding hemispace with hemifield) to manipulate the attentional gradient. That is, *covert* attention was used to manipulate the attentional gradient.

The terms "attentional gradient" and "covert attention" need to be clarified. Kinsbourne (1970) attempted to account for lateral cerebral asymmetries in terms of attentional gradient to one side or the other of visual fixation. However, he did not specify what he meant by *attention*. He simply noted that while subjects can be visually fixated on one point, they can selectively attend to other points in their visual field. One might then assume that attentional gradient may be indexed by horizontal retinal eccentricity; in other words, by VF. *Overt* attention would then occur when fixation coincides with the attended stimulus; *covert* attention occurs when fixation and the attended stimulus are not coincident but the subject knows where the stimulus is or where it will appear. This definition of overt and covert attention is essentially the same as that given by Posner (1980): "Orienting to positions in space can be obtained covertly through movements of attention or overtly through shifts of head or eyes." (p. 12). The definition given by Hellige (1993) is similar: "One important distinction is between *overt* shifts of visual attention (involving shifts in eye fixation) and

covert shifts of visual attention (looking at one point and attending to another)." (p. 103).

So far, no investigations have compared blocked to randomised stimulus presentation while manipulating *overt* attention. That is, instead of presenting the trials into one VF or the other, the stimulus appears in one hemispace or the other and the subjects direct their gaze in the appropriate direction. But predictions made for the covert situation can readily be extended to the overt. Assume that holding a steady GP will maintain a steady arousal of the contralateral hemisphere, and further assume that it requires some time for the arousal to build up and to decay. It seems reasonable to expect that blocked presentation of trials to one GP will produce a greater degree of arousal than will occur if the trials are randomized among the GPs. Consequently, the performance of the contralateral hemisphere relative to the ipsilateral hemisphere should be further enhanced under blocked (B) compared to randomized (R) conditions. Since a crossover GP x VF interaction is already expected, by including B and R GP conditions as factors, a Condition x GP x VF interaction should be found with the greatest magnitude of the effect occurring under B conditions.

It should be noted that while a GP x VF interaction is expected when testing Kinsbourne's models, a GP main effect is not expected (but not excluded). However, if centre VF (CVF) presentation is used, a GP main effect might be

expected if the processing was to be done by the putatively specialised hemisphere. The specialized hemisphere, having direct access to the stimuli, would be favoured to perform the task regardless of GP. Thus, the observed results would reflect solely the functioning of that hemisphere plus any improved performance due to GP. Hence, performance with CVF presentation should mirror that of the VF connected to the specialized hemisphere. If, however, a GP main effect occurred for the CVF in the absence of a corresponding simple main effect for one or the other divided VF condition, this would imply that CVF performance was unrelated to that of the individual hemispheres. Such a result would pose serious problems for the CLEM model, the attentional gradient model and the general notion of cerebral laterality.

Along with the main parameters of GP, VF and condition, two other parameters, task difficulty and task modality, lend themselves admirably to the investigative programme. It was noted earlier that while simple questions requiring overlearned responses did not appear to elicit CLEMs, a systematic investigation of the effects of task difficulty has never been undertaken. Studies relevant to the question are confusing and contradictory, due, in part, to the differing emphases of the investigators. What is consistent is that all reported that task difficulty, despite differing ways of assessing it, affected ocular motility or saccadic extent. The most extensive and consistent findings were due to May et al. (1990) who reported that both saccadic extent

and task performance decreased linearly with increasing difficulty under forced eye movement conditions.

Kinsbourne's models do not appear to provide any basis for making predictions about a GP x difficulty interaction; arousal of one hemisphere simply facilitates task performance by that hemisphere. Nothing is said about the process by which prior arousal facilitates task performance. Is it a simple additive process such as would occur if the effect was independent of the task process itself? For instance, if its effect was solely to reduce the rise time of task related activation, then GP would produce an almost constant effect on, say, RT as the dependent measure. Then, as task difficulty increases, indexed by longer RTs, the GP component would decrease proportionately. So GP effects would more readily be found for simple tasks with short RTs rather than more difficult ones. On the other hand, a GP effect might act multiplicatively with the time required to complete the task. In this case, a constant GP effect would be evident at all levels of difficulty. Another possibility is that a GP effect is *proportional* to difficulty. In this case the GP effect would become an increasing proportion of RT as difficulty increased. Hence, the effect would be more easily seen with difficult tasks than simple ones. It is difficult to chose among the alternatives on theoretical grounds and it would appear that a GP x difficulty interaction is at present a strictly empirical matter.

The final parameter to be considered is modality, that is, the verbal or visual-spatial emphasis of the task. There are several lines of evidence (Ehrlichman & Weinberger, 1978; Hiscock, 1986) that indicate that the directions of CLEMs are influenced by the modality that is involved. Horizontal CLEMs are most closely associated with VQs while SQs tend to give rise to stares or vertical CLEMs; ocular motility is suppressed by SQs and increased by VQs while induced OKN is differentially affected by both VQs and SQs and in proportion to their admixture. Also, in the review of reverse CLEMs (p. 54), it was noted that several studies reported results that were different to, but consistent with, predictions made from Kinsbourne's models. For example, Walker et al. (1982) found, as expected, a contralateral performance increment with VQs, but an ipsilateral performance decrement occurred for SQs rather than a contralateral increment. The available empirical evidence suggests that central and vertical GPs will influence the results obtained with SQs more than those for VQs. At the same time, horizontal patterns of facilitation and retardation might differ for the two modes. Kinsbourne's models, however, do not allow any really useful predictions to be made about GP and modality.

Kinsbourne (1970; Kinsbourne & Hicks, 1978) makes it clear that he regards the two cerebral hemispheres as functionally specialised with their functional efficiency being modified by attentional factors. But, with divided field presentation, the effects of any one modality will be the

same for all GPs. Hence, the only prediction to be made for modality from Kinsbourne's models is that an appropriate main effect for VF will be superimposed upon the predicted GP x VF interaction. In other words, the usual VF advantages due to mode should be evident in all GPs.

To summarise, the research programme was intended to investigate the possible functional utility of reflective CLEMS. This was to be done using GP as the independent variable to address a number of substantive issues within the domain of attention and functional cerebral laterality. These issues were to be considered within Kinsbourne's cerebral laterality and functional distance models of CLEMs. They were also to be considered further as special interest topics within Kinsbourne's (1970) lateral attention gradient model of functional cerebral laterality. For this latter purpose GP was to be used to manipulate the attentional gradient, an experiment that has never previously been reported. At the same time, a comparison between CVF and divided VF stimulus presentation was expected to provide further tests of the models. Concurrent with these primary investigations, the effects of task difficulty and modality were to be explored.

The experimental paradigm was to vary systematically the direction of subjects' GP away from a central position while they carried out a divided VF, two choice RT task. In this way a representative sample of all possible CLEMs could be

investigated with the stimulus information being restricted, at least initially, to the targeted hemisphere with clearly identified task requirements. If GP is an integral part of cognitive functioning, controlling eye position should have some effect on RT. But if CLEMs are simply an epiphenomenon of cognition, no effects should be found.

Experimental Programme

Methodological rationale

The basic experiment was structured so that full advantage could be taken of the potential methodological improvements outlined in the Introduction. To this end, the subject's GP would have to be known to the experimenter and held constant over the entire interval bounded by task presentation and responding. The task would have to be of known content and primarily involve only one modality, either visual-spatial or verbal processes. These processes in turn would be restricted mainly to the one targeted hemisphere. As an added requirement the task should restrict the range of processing strategies available to the subject. To satisfy these requirements a battery of simple tasks was assembled, suitable for divided VF presentation and using RT as the response measure.

One aspect of the logic underlying this procedure deserves emphasising. That is, a simple task/response combination was expected to provide few opportunities for subjects to introduce their own idiosyncratic processing variations. Also, using a brief stimulus display and speeded responding would push subjects to their performance limits, again minimising the opportunity for variations in processing strategies.

Stimuli and fixation points were shown on visual display units (VDUs) which functioned as tachistoscopes. The VDUs were arranged in a 3 x 3 rectangular grid so that the outer fixation points subtended a horizontal visual angle of 50 degrees and a vertical angle of 35 degrees. The VDUs forming the central row and column lay on the subject's horizontal and medial visual planes respectively (Figure 1). The centre of each VDU represented one GP. Any or all GPs could be used in an experiment although only one was used for any individual trial.

	LEFT	CENTRE	RIGHT
TOP	E	1	E
MIDDLE	2	3	4
BOTTOM	E	5	E

Figure 1. Schematic of the VDU display seen from the eye position. Numbers refer to the individual GPs; E indicates unused positions

The logic of this design was that the VDU array provided a representative sample of all the possible directions that CLEMs could take, with the central position acting as both a stare position and as a baseline. The selected visual angles allowed the stimuli to be presented near to the extremes of the comfortable binocular visual field. True binocular viewing of the stimuli was necessary because the crossed

nasal neural pathways are more efficient than the uncrossed
temporal pathways (White, 1969). Monocular viewing of the
outer stimuli would have occurred had the subject's nose
blocked the contralateral temporal retinal hemifield, thereby
biasing the RTs to an unknown degree.

Presenting the stimuli to one VF guaranteed that the
information was received by only one cerebral hemisphere and
that the initial processing was done by the visual system.
While there is no certainty that the processing would be
restricted to the one hemisphere, after reviewing the
evidence Sergent (1983) concluded that under presentation
conditions similar to those used here, processing is
primarily carried out by the hemisphere receiving the
information. Support for this opinion comes from Ragot and
Lesevre (1986) who, using electro-physiological measures to
study S-R compatibility, demonstrated that in a divided
field, two choice RT task, processing was restricted to one
cerebral hemisphere.

There were other factors to be taken into account in deciding
upon the exact form of the task. If the task were to be made
too easy in an effort to restrict the subject's processing
strategies, the response may have been stimulus driven. That
is, responding may have been governed solely by the stimulus
and excluding any high level processes (Johnson & Dark,
1986). Therefore, tasks were chosen so that a solely
stimulus driven response would be avoided but with too little

stimulus information to provide alternative processing options.

The combination of brief stimulus exposure, retinal eccentricity and speeded responding made the task into one that was both stimulus and resource limited. That is, the subject was limited in the quality of the stimulus information available, and in the cognitive resources that could be used (Sergent, 1983). This could be expected to assist in restricting the subject's processing options.

The choice was aided by Sergent's (1983) four level classification of the difficulty of tasks used in tachistoscopic studies of cerebral laterality. In ascending order these are detection, simultaneous matching, recognition and identification. These levels can be combined or modified by other tasks to produce overlap of difficulty between levels. For example, the fairly simple task of deciding whether or not two simultaneously presented polygons are the same can be rendered more difficult by presenting them at differing angular orientations. The resulting difficulty level may then be greater than the simple identification task used in Andreasen (1988).

An example where difficulty levels are combined is a Posner (1969) type task in which upper and lower case letters are presented simultaneously to subjects who are required to indicate whether or not they are examples of the same letter.

Here, simultaneous matching is combined with identification to yield a more difficult task than simple identification.

The task used in Andreasen (1988) was the identification of two (overlearned) upper case letters, X and V. This was intended to be at the lower end of Sergent's (1983) fourth level of difficulty, namely, identification. It can be argued, however, that letters are so overlearned that no higher cognitive processes are involved, which means that the task was simple S-R association. Hence, the reported GP effect may have been due to interaction of eye movement with perception, or responding, or both. This possibility can be tested by comparing the results with those obtained by using a task that includes a cognitive component.

Bearing all the aforementioned considerations in mind, a number of two choice RT tasks were selected for use in the present series of experiments. The simplest required the subjects to distinguish between a vertically and a horizontally oriented rectangle. A slightly more complex task was the two-letter identification task used by Andreasen (1988). Cognitive complexity was considerably greater for the remaining two tasks. One was a lexical decision task (words/non-words) while the other was a mental rotation task using a cartoon face. These tasks were to be used in conjunction with a within-subjects experimental design.

In summary, the experiments were designed to maximise the experimenter's control over the relevant variables; eye position, task content, hemispheric involvement, processing modality and processing strategies. In addition to these variables, efforts were also made to control potential methodological confounds that might give rise to confusing interactions or misleading statistical tests. The earlier experiments served to address some of the methodological and design problems that had been identified. For the sake of continuity, consideration of these problems, along with others associated with the overall program, will be deferred until after reporting and discussing the results of the experiments.

Basic experimental procedure

Equipment

Up to nine Hewlett Packard (HP) Visual Display Units (VDU:HP35731B) with tiltable screens could be used to present the stimuli. An HP9000 Series 300 computer and HP 6944A multiprogrammer were used to control the VDU displays, the trial x trial sequencing, and to obtain RTs. Also used were a two-way response key pad and a foot switch[3] that was used as an external trigger to initiate each trial sequence. A Techtronix T65232 narrow beam luminance probe was used to

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[3] Response pad and switch were made in the Massey University Psychology Department workshop.

measure the VDU screen luminosity and a Seconic studio light meter (Model 28-C) for assessing the ambient light intensity.

Arrangement

The VDUs sat on three curved shelves arranged one above the other. Each shelf could carry three VDUs (Figure 2). A forward extension of the shelf frame carried a head restraint incorporating a universally adjustable bite bar, and also a shelf that supported the response key pad. The bite bar was shielded by a 10 cm length of reusable silicone rubber tubing. The head restraint was securely braced to the outside of the shelf framework and had attachment points for an eye positioning jig and a VDU alignment jig. The shelves carried sloped bases with locating holes to assist in positioning the VDUs. The framework forward of the shelves was enclosed on the sides, top and the VDU shelf end with sheets of hardboard. The VDU screens were seen through holes cut in the hardboard. Nine holes were cut, corresponding to the GPs of Figure 1, and shaped to allow the VDU screen frames to protrude and be adjusted for alignment. Three wings were hinged to the frame at the viewing end; a vertical one to each side of the subject's head, and a horizontal one above the subject's head. These wings prevented distraction by extraneous light sources. All surfaces visible within the enclosed framework were painted matt black, and all cracks that allowed distracting light to enter were blocked off.

Side elevation

30°

1.17 m

1.23 m

Response pad
External trigger

Floor level

VDUs

Plan view

Head restraint
and
viewing position

50°
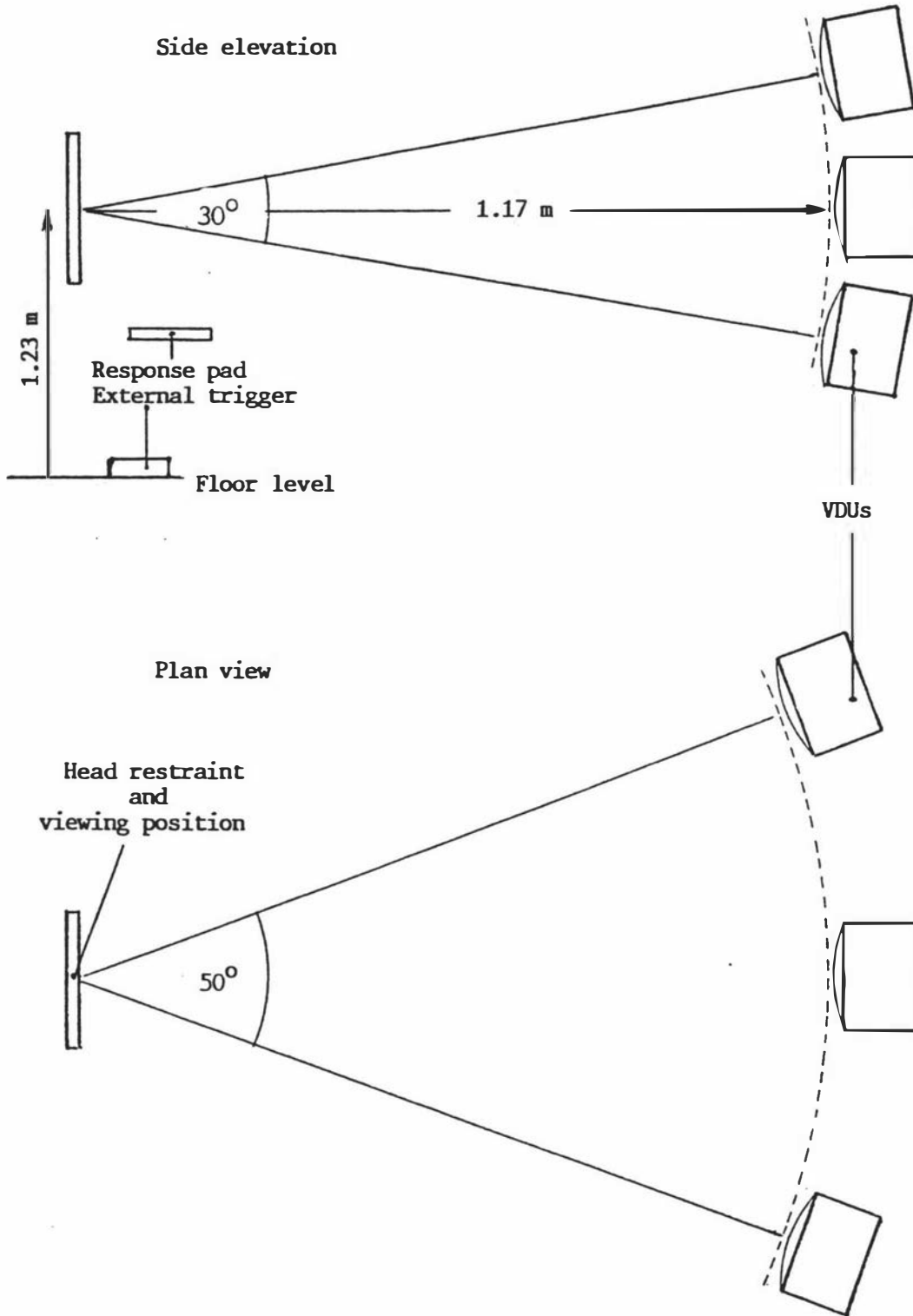
Figure 2. Schematic of the VDU array showing the relat-
ionship of the fixation points to the viewing position.

To avoid the need for a long period of dark adaption, low intensity diffused light was allowed to enter the apparatus by shining a 60 watt white light bulb onto a buff coloured wall at the rear of the apparatus. Reflected light entered through the unused VDU apertures which were covered with white drawing paper. The only other light source (other than the VDUs themselves), was the monitor of the computer that was used to control the experiment. Under these conditions no reflections were visible on the unlit VDU screens. The ambient light intensity at the viewing position was too low to be measured using a photographer's light meter (Seconic studio light meter, Model 28-C)

The subject sat in an upholstered typist's chair that had gas operated height adjustment and a coarse/fine horizontal positioning facility. The coarse adjustment was obtained by placing the chair on a 0.6 m X 1 m baseboard fitted with rollers on the underside. This board was simply pushed into position against a pair of stops attached to the viewing framework. A guide track was fastened to the top of the board and aligned with the longitudinal axis of the viewing frame. One of the chair wheels ran in this track. A long coarse feed screw mounted in bearings fastened to the top of the baseboard passed through a nut welded to the chair base. Turning the screw gave fine control of the chair's horizontal movement over approximately 0.3 m travel. The coarse adjustment allowed the subject easily to leave and enter the viewing frame during rest breaks. The fine adjustment

prevented possible injury being caused by ramming the subject's eyes against the eye positioning jig. Loose packing was used for comfortable foot and forearm support.

The eye positioning jig was a length of flat steel, long enough to span the head restraint framework, and with two 5 cm lengths of wooden dowel screwed to one side of it. The dowels were 6.5 cm apart and their outer ends were centre dimpled. The jig could be quickly attached to the frame using a pair of wing screws. When attached to the frame, the dimpled ends of the dowels, which faced away from the VDUs, represented the correct viewing position.

The fixation point in GP3 was the basic reference point and was 1.23 m above floor level (Figure 2). The eye position was set at 1.17 m horizontally from this point. The eight outer VDU positions were located so that a notional fixation point, located at the centre of each GP lay on the visual sphere defined by the eye position and the reference point. The fixation points in the left and right columns subtended a nominal horizontal visual angle of 50 degrees, those in the top and bottom rows subtended a nominal vertical angle of 35 degrees. These angles were chosen to allow the outer fixation points comfortably to approach the limits of the subject's visual field while retaining binocular viewing of the outer stimulus positions.

The VDUs were aligned so that their screens were tangential to the predetermined visual sphere and their centres were at the intended GPs. With an accurately built framework, correct alignment was achieved by using a special jig in conjunction with the VDU display movement. The jig was basically a graduated, lockable telescopic rod. One end carried a universal ball joint attached to a steel "top hat" bracket. This bracket was attached to the head restraint at the same fastening points as the eye positioning jig, and held the ball joint at the centre of the viewing position. The other end of the rod carried a four armed metal windmill that was free to rotate and slide on the rod. The windmill arms were made of steel rod and were lathe machined to be square to the telescopic rod and to each other. They were long enough to rest on the rim of the VDU screen surround. A rubber plug was inserted into the end of the rod to protect the VDU screens.

The geometric centres of the screens were located and marked with a felt tip pen. After the VDUs had been aligned at their approximate positions, the alignment jig was attached to the frame, extended and locked at 1.17 m. The VDU was moved until the screen was firmly in contact with the rubber tip of the jig, at the marked screen centre. The screen was then tilted and turned in its mountings until its rim was in contact with all four arms of the windmill.

When all of the screens had been adjusted, the fixation points were displayed and their relative positions were checked by measurement. Further adjustments using the jig were made as required. All angles and distances were then checked and measured independently using an infrared theodolite, accurate to 1 sec of arc. The horizontal and the vertical pairs of fixation points were symmetrically located about the central fixation point, to within 15 minutes of arc. The fixation points defining the individual GPs subtended 52 degrees horizontally and 35.5 degrees vertically. The difference between the actual angles and the intended angles of 50 and 35 degrees respectively was regarded as unimportant.

Trial sequence and control

The entire trial sequence was controlled by the computer. This included the selection of the GP x VF x Stimulus combination for any particular trial, trial sequence and response timing, and data recording.

Experimenter-controlled trials

At the commencement of a block of trials, the fixation point appeared on a computer-selected screen. When the subject verbally indicated that fixation had been achieved the computer initiated the trial sequence. One sec after the computer beep the stimulus was displayed in one VF for 50

msec[4] whereupon a solid mask appeared (all pixels on)
lasting for 1 sec. Subjects responded during the response
interval which lasted for the duration of the masking
interval. Responses were made using the left or right middle
finger to close the appropriate response key. A computer
beep signalled the start of another trial sequence 500 msec
after the mask offset. Figure 3 shows the sequence of events
occurring within a trial. Responses made outside the
response interval were deleted by the computer and
replacement trials added at the end of the experiment.
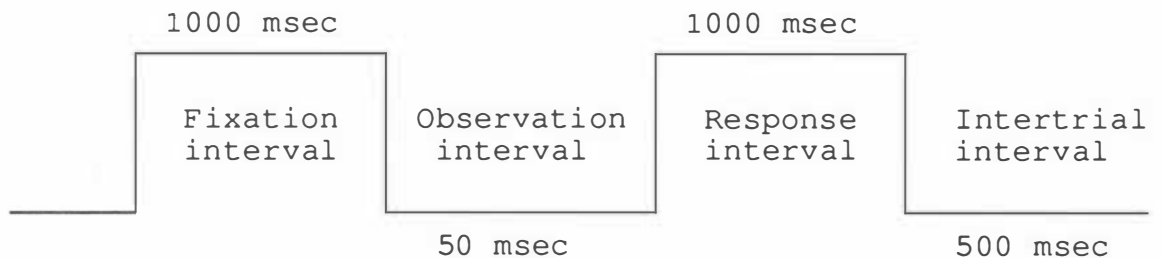
Figure 3. The trial sequence.

Self-paced trials

A computer bleep signalled that a fixation point (single
pixel) had appeared on one of the VDUs. The subject located
it using eye movements only, the head being restrained by the
bite bar. When the gaze was steady, the subject initiated a
trial by closing the external trigger with the right foot.
After a delay of 1 sec the stimulus appeared for 50 msec
followed by a combined masking and response interval lasting

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[4] Details of the method used to time the display are given
in Appendix 1.

for 1 sec. Half a sec after the mask was cleared, a bleep
signalled the beginning of a new trial sequence. Except for
the subject initiating the trials, the sequence and
conditions were the same as for the experimenter-controlled
trials.

The block diagram shown in Figure 4, below, illustrates the
manner in which the self-paced sequence was controlled.
Closing the external trigger with the foot initiated the
computer-controlled timing *via* the timer pacer. After a
delay of 1 sec this caused the stimulus option to be
displayed for 50 msec before masking. Closing the response
key altered the voltage in the key circuit which was
continuously monitored by the FET scanner (1000 scans/sec).
The FET scanner fed the analogue voltage to an A/D conv-
erter, which sent a digital signal to the memory buffer. The
memory buffer held the data for later processing by the
computer. Except for transferring the function of the
external trigger to the computer, the experimenter-controlled
trials followed this same process.

Analysis

It was decided that the major analyses[5] would consist of two
planned comparisons, one involving the horizontal GPs (GP2,

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[5] All analyses were done using SAS software (Copyright
1989. SAS Institute Inc., SAS Campus Drive, Cary, NC USA) or
customer tailored programmes written by Massey University
Computer Services.
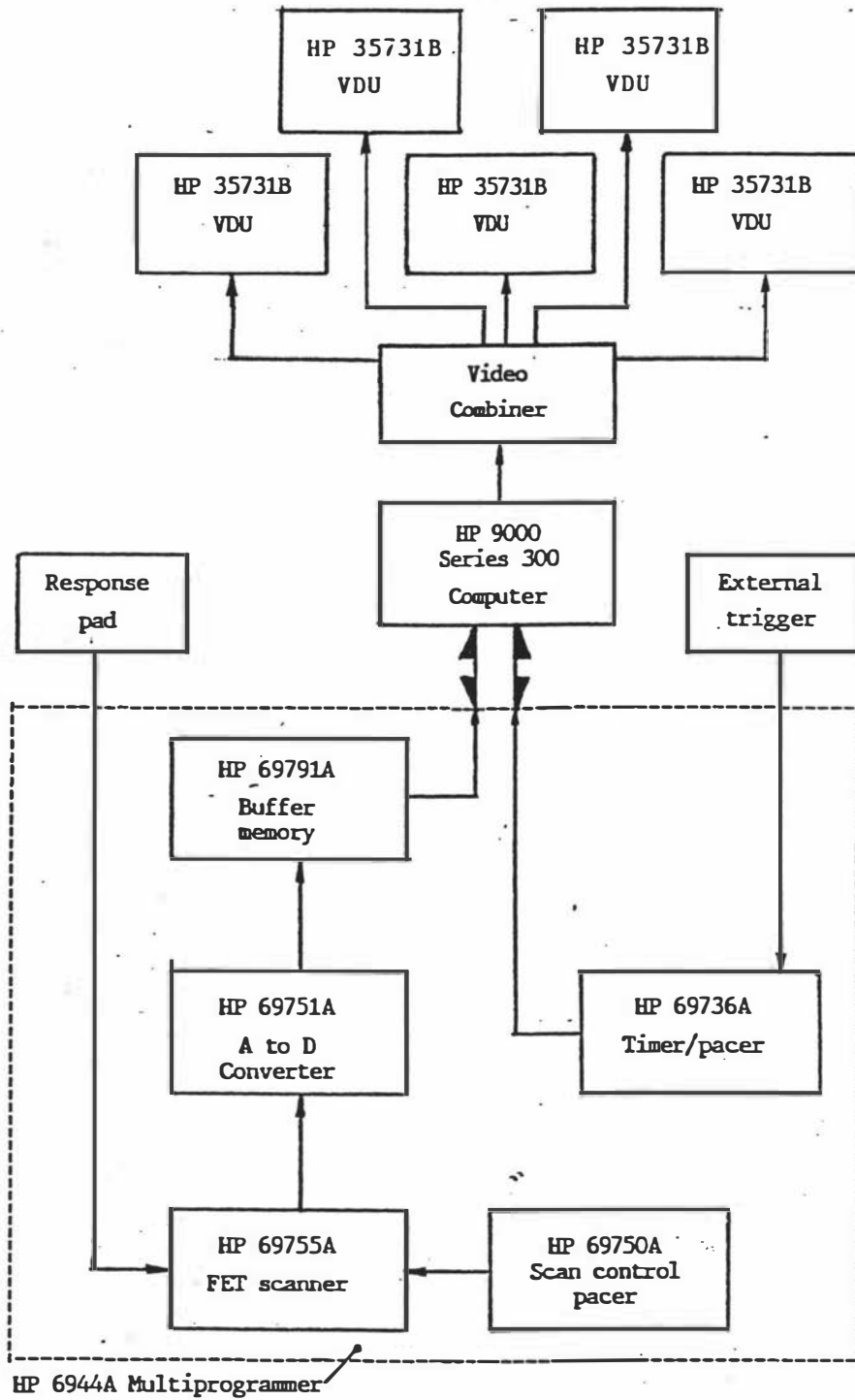
Figure 4. Block diagram of the experimental control system. (See text for details.)

GP3, and GP4), the other the vertical GPs (GP1, GP3, and GP5). This decision was taken because with four factors being varied (trial presentation Condition, GP, VF and Stimulus) over several experiments, the possibility of trivial or spurious effects being found was unacceptably high. Also, within an experiment, the effects of the stimuli were irrelevant to the goals of the overall programme and any such effects would complicate unnecessarily the interpretation of the results. So, to further simplify matters, the initial analyses of each experiment consisted of an omnibus ANOVA with, where appropriate, the Dunnett test (Keppel & Zedek, 1989) being applied to any Stimulus and/or Stimulus interactions. Throughout the analyses median RTs were used as the summary statistic.

Experiment 1

Method

Experimental hypotheses and design The central question being addressed was, "Are CLEMs functionally related to cognitive processing?" If they are then at least some of the many possible GPs should affect cognitive processing. So, replicating Andreasen (1988) and testing Kinsbourne's models of CLEMs were the main objectives of this experiment.

The logical predictions from Kinsbourne's models when GP is varied were considered earlier (p. 69). There it was shown that a crossover GP x VF interaction should be found over the horizontal GPs. In the interaction, facilitation should be shown when the left GP coincides with LVF presentation and, conversely, the right GP coincides with RVF presentation, that is, when VF and GP are congruent. (Facilitation is inferred from shorter RTs when RT is the dependant measure.) A vertical GP main effect without any GP x VF interaction was expected over the vertical GPs where the GP effect was expected to be a relative speeding of RTs on the upper and lower GPs compared to the central GP. This was expected because vertical movements are bilaterally controlled thereby leading to symmetrical arousal of the cerebral hemispheres and hence facilitation when the eyes are moved away from the central GP.

The predictions from Kinsbourne's models are contrary to the results of Andreasen (1988). There, the crossover GP x VF interaction that was found over the horizontal GPs gave shorter RTs when either right GP and LVF, or, left GP and RVF coincided. Furthermore, over the vertical GPs, RTs from the lower GP were found to be longer than the central and upper GPs. This latter result was consistent with other empirical reports that upward CLEMs and stares were the most reliable companions of SQs. If stares and upwards CLEMs are functional accessories to the processing required by SQs, then RTs would be expected to be shorter when looking upwards

or straight ahead rather than elsewhere when stimuli were visually presented. This would arise if visual perception and imagery share a common neural substrate (Farah, 1984). Consequently, if a verbal task were to be presented visually, GP effects due to both verbal cognition and visual perception should be found.

Within the one experiment, then, two alternative hypotheses were to be tested. For the first, based on previous research, it was expected that a vertical GP would have a significant effect on RT. For the second, derived from a theoretical model, a significant GP x VF interaction over the horizontal GPs was expected with RTs being fastest when VF and GP were congruent. Additionally, when the model is extended to vertical movements, faster RTs were expected in the upper and lower GPs compared to the central GP.

The experiment designed to test these hypotheses consisted of five GPs, two VFs, and two stimuli giving 20 conditions. Within the experiment all conditions were randomized, with an equal number (26) of all 20 possible stimulus combinations appearing on each VDU, or 520 trials in all.

Subjects Ten subjects were used, five male and five female, aged from 21 to 37 years. All were volunteers drawn from a pool of senior psychology students. All were right handed with normal or corrected for normal vision (contact lenses). An extra requirement was that the nose and eye ridges did not

prevent normal binocular vision of the outer stimulus positions. This was checked *in situ* and a number of potential subjects had to be rejected. All were naive as to the experimental hypotheses.

Equipment Five VDUs and the external trigger for self-paced trials were used. The VDUs occupied GPs 1,2,3,4, and 5 (Figure 1).

Stimulus display The fixation points, a single illuminated pixel, were set at the centre of each of the VDU screens. The screen contrast was set to give zero background luminance in a darkened room; the luminance of a 5 cm square test display (all pixels on in the test square) was set at 5 lux. This was checked before each session with the luminance probe located at the eye position. The ambient luminance at the eye position was too low to be measured using an ordinary photographer's light meter.

The idiosyncrasies of the VDU display screen played a major role in the choice of stimuli for the following reason. Simple, overlearned, readily discriminable stimuli were needed to satisfy the criteria outlined earlier (p. 79) and capital letters were an obvious choice. Unfortunately, most letters showed bright bars or spots of light which would allow subjects to make their decisions on variables other than shape. Also, to further restrict processing options, the letters had to be equalised in terms of their component

parts, that is, bars, curves, etc. The letters "X" and "V" proved to be an acceptable pair.

Each stimulus was 1 cm high and only one appeared on each trial. It appeared with its centre at 6.5 cm from the fixation point giving a retinal eccentricity of three degrees. The stimulus was exposed for 50 msec and was immediately followed by a solid mask (all pixels on) lasting for 1 sec. Both the retinal eccentricity and exposure duration were well within the ranges commonly used to ensure that the stimulus engaged only the contralateral hemisphere (Sergent & Hellige, 1986). Stimulus exposure duration and RT were accurate to within one msec.

Procedure The VDU luminances were checked and adjusted as necessary prior to each session and a freshly sterilised length of silicone tubing was fitted to the bite bar. The subject was seated in front of the display and motivating instructions with experiment justification given. The bite bar and chair were adjusted to allow the subject to look directly along the horizontal base line at the central VDU fixation point and with the eyes at the designated viewing point. This was done by making adjustments until the subject reported that the dimples in the end of the eye positioning jig were directly in front of the eyes. This was checked by the experimenter who could see both pupils and dimples from the side. The distance was accepted as correct when the subject's eyelashes just flicked the end of the jig. The

bite bar was adjusted so that this position could be maintained throughout the session. The idealised objective was to have the subject looking along the baseline with both head and eyes in the natural resting position. Physical comfort was obtained by using suitable loose packing beneath the feet and forearms. The foot and foot switch were adjusted so that when the switch was closed the foot returned automatically to a comfortable rest position. Considerable attention was paid to the subject's comfort, especially the arms, neck and shoulders. Discomfort in these places would provoke head movement during the experiment or interfere with responding. The procedure was then demonstrated and the subject was allowed a block of familiarisation trials. Adjustments were made on demand during the practice trials. No adjustments were made after the experimental trials began and the subject was asked to remember the final adjusted position in order to reinstate it after the rest periods. After the initial adjustments had been made and before the practice trials, a test was made of the subject's ability to see the outer stimuli with both eyes when the head was centred. A number of subjects were rejected at this point due to the outer stimuli being obstructed by the nose.

Responses were made using the middle finger of each hand to close a response pad. Each stimulus was uniquely paired with one finger, the pairings for the first session being alternated across subjects. The stimulus/finger pairs were reversed for the second session.

Immediately before the practice trials began the following
instructions were given to the subject:

> "I want to emphasize three things. Speed between
> trials is not to be aimed at. Let your eyes settle
> down and focus properly on the fixation point. Take a
> few seconds for this; I'll be reminding you of this
> because once into a rhythm, one tends to speed up.
> Secondly, don't try to anticipate or second guess the
> computer. Every trial is independent of all others on
> all three variables, eye position, visual field and
> stimulus. Thirdly, keep your head still and move only
> your eyes".

The final instruction was emphasized. The essentials of
these instructions were repeated before the experimental
trials began and again at the end of each rest period.

Practice trials were then given in blocks of 18 until a
criterion performance of two successive error free blocks
were achieved with a minimum of 90 trials per subject.
Practice trials were given using all five VDUs and coaching
with respect to errors and reductions in RT was provided.

In each experimental session, subjects received a total of
520 trials given in blocks of 52. Both stimuli occurred 26
times in every GP X VF combination. The trials were rand-
omised across all conditions, the one restriction being that
none of the three variables, GP, VF or Stimulus, took the
same value on more than three successive trials. A break of
one minute was given after every block of 52 trials and a 10
minute break after 260 trials had been completed. Each
subject attended for two sessions, a morning and an afternoon

one, to counterbalance for any circadian effects. The second session was held within three days of the first session.

Results and Discussion

The raw RTs were culled of double responses and responses made outside the response interval. The resulting individual RTs were sorted into the 40 session x response hand x stimulus combinations and examined for response errors, a mean error rate of 4.2% (s.d.=2.3) being found. Visual inspection of the cell counts revealed no systematic distribution patterns for these errors and they were not further analyzed. Individual median RTs, each based on 26 trials, were extracted for each condition and used in all subsequent analyses (Appendix E1: Table 1)[6].

Stimulus effects were not expected to occur[7], but as a check upon the validity of this assumption the individual raw data were averaged across sessions and a three-way (GP x VF x Stimulus) ANOVA carried out. The Dunnet test was used

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[6]Individual mean median RT data and ANOVA tables for this and all other experiments are given in separate appendices. Space constraints made it necessary for some of the Factor names to be abbreviated. A list of the abbreviations used can be found at the beginning of the appendices on p. 259

[7] To check on the effectiveness of the counterbalancing, the median RTs were analyzed in a five-way mixed ANOVA with the initial Response/Hand-Stimulus combination as the between-groups factor and Session, GP, VF and Stimulus as the within groups factors. The relevant Hand x VF x Stimulus interaction was significant, $F(1,8)=15.02$, $p<0.005$ (Appendix E1: Table 2). When the RTs were collapsed over sessions and reanalysed, the corresponding VF x Stimulus interaction (Appendix E1: Table 3) was not significant.

partitioning the 0.05 *alpha* level at 0.02 for the stimulus main effect and 0.01 each for the two-way and one three-way interactions. No effects involving Stimulus were significant (Appendix E1: Table 3). There being no stimulus effects to consider, the separate stimulus RTs were collapsed and the mean median RT for each of the resulting 20 Session x GP x VF conditions were used in the subsequent analysis.

Planned comparisons were then carried out separately across the horizontal GPs (2, 3, 4) and across the vertical GPs (1, 3, 5). Group mean medians for each individual VF are shown in Table 1.

Table 1. Mean median RTs and their standard deviations (s.d.) for each GP x VF combination. Combined VF values are also shown.

GP	LVF Mean	LVF s.d.	RVF Mean	RVF s.d.	Combined VF Mean	Combined VF s.d.
1	418.65	58.92	413.75	59.83	416.20	57.84
2	417.85	60.91	406.20	53.55	412.02	56.14
3	418.95	65.14	412.70	56.55	415.82	59.45
4	414.25	59.62	413.65	54.53	413.95	55.61
5	424.85	61.25	417.65	58.06	421.25	58.20

Over the horizontal GPs, the LVF differed little as GP varied. However, RTs for the RVF were faster for the left GP (GP2) compared to the other GPs (GP3 and GP4). This GP x VF interaction was significant, $F(2,18)=7.51$, $p<0.005$ (Appendix

E1: Table 4). Multiple *t* tests for correlated samples
revealed that the interaction was due to the RVF being
speeded by almost eight msec in GP2 (left) compared to GP4
(right), *t*(9)=1.99, p<0.05. However, the strength of
association, w^2(omega squared: Hays, 1973), was found to
account for only 3.9% of the experimental variance and just
0.6% of the total variance, with subject variance accounting
for 83.5 % of the total. The LVF was retarded by four msec
in GP2 compared to GP4 but this difference was not
significant.

Across the vertical GPs the bottom GP (GP5) was retarded
compared to GP1 and GP2, but the difference did not quite
reach significance, F(2,18)=3.22, p<0.07. w^2 accounted for
1.8% of the experimental variance and 0.3 of the total
variance. (Appendix E1: Table 4).

In this experiment the predictions from Kinsbourne's models
were not supported. Across the horizontal GPs, the expected
GP x VF interaction, where faster RTs should occur when GP
and VF are congruent, was not found. Instead, the results
were consistent with Andreasen (1988) where the incongruent
GP x VF combinations produced the faster RTs. Likewise, RTs
from the vertical GPs did not support Kinsbourne's model
which predicts facilitation for both VFs in the upper and
lower GPs. The trend towards slower RTs in the lower GP was,
however, similar to the GP effect found by Andreasen.

Replicating the essential results of Andreasen (1988) confirmed that using GP and VF as independent variables is a worthwhile technique. The next experiment was designed to extend the application of the method by comparing blocked (B) and randomized (R) GP presentation conditions. By doing this, one of the substantive predictions from Kinsbourne's (1970) attentional gradient theory could also be tested. The prediction was that the GP x VF interaction would be larger under B conditions than under R conditions. This comes about because a steady GP is expected to produce a greater degree of arousal within the contralateral hemisphere than would occur when the GP is continually changing.

Experiment 2

Method

The basic design was a within-subjects comparison between the fully randomized condition of Experiment 1 and a condition where trials were blocked onto each GP in turn.

Subjects Ten subjects, eight male and two female, were recruited from university staff and students, age range 19-40 yrs. Subjects received a small honorarium for participating in the experiment.

Equipment and Procedure The equipment was the same as was used in Experiment 1. In that experiment the criterion performance for the practice trials was found to be unnecessarily stringent; accordingly the criterion was relaxed to a 5% error rate over the last two blocks of practice trials. Also, the warning beep was shortened to 100 msec and lowered in frequency.

The R conditions were exactly as for Experiment 1. The same general procedure was used for the B condition but with the following modifications. Practice trials were given in blocks of 18 on each VDU in turn, each screen being used once in a random order. A minimum of 90 practice trials were given at the beginning of each session using the same performance criterion as for the R condition. Experimental trials were presented in blocks of 52 on each VDU in turn. The VDU sequence was randomly selected at the beginning of each B session, each screen being used twice giving a total of 520 experimental trials for the session. Within each block a short (roughly 10 sec) break was given after 26 trials to reduce the fatigue due to staring fixedly in one direction.

Each trial was completely controlled by the computer and the trial sequence was as described earlier (Figure 3). Other than the mid-block break where subjects were instructed to roll their eyes, rest breaks were the same as for the R conditions.

Subjects attended for four sessions, each session lasting for between one and a half and two hours duration. Half of the subjects received an RBBR sequence, the remaining subjects receiving the alternative BRRB sequence. Due to a mechanical failure, two subjects received an extra block of trials during one of the sessions. Additional difficulties arose due to the personal schedules of the subjects and incidental injuries to the experimenter. As a result, most subjects took about three weeks to complete the experiment but in three cases two months were needed.

Results and Discussion

The raw RTs were sorted by GP x VF x Stimulus x Session x Condition (B, R) for each subject. These were then examined for errors and a mean error rate of 5.5% (s.d.= 2.1) was found, the errors being evenly distributed across all experimental conditions. As in Experiment 1, median RTs for the 26 trials for each condition were used in the subsequent analysis. The individual mean median RTs are listed in Appendix E2: Table 1.

A preliminary analysis with Stimulus as a factor produced no effects involving Stimulus (Appendix E2: Table 2), so the RTs for the two stimuli within a session were collapsed to give a single mean median RT for each GP x VF condition. These mean median RTs were used for the remaining analyses.

To evaluate the effect of counterbalancing the presentation conditions, a four-way mixed ANOVA was carried out with Order as the between-subjects factor and Session, GP, and VF as the within-subjects factors (Appendix E2: Table 3). There was a significant main effect for Order, $F(1,8)=8.43$, $p<0.02$, with the BRRB order being some 65 msec faster overall than the RBBR order (Table 2). There was also a significant Order x Session interaction, $F(3,24)=3.89$, $p<0.03$. RTs for the BRRB order tended to vary about the mean for the sessions, whereas the RTs for the RBBR order increased fairly steadily over sessions. However, since the patterns of RTs over Order and Session was essentially the same for both vertical and horizontal GPs, only the overall RTs are shown in Table 2.

Table 2. Mean median RTs (msec) for counterbalanced order as a function of session order.

	Order	
Session	BRRB	RBBR
1	402.69	433.65
2	367.11	448.17
3	397.40	445.48
4	379.67	470.52
Mean	384.22	449.46

Order and Session did not interact with either GP or VF, and since neither Order nor Session was theoretically relevant to the experiment, the data were collapsed over both factors for

the remaining analyses.   Group mean medians are shown in
Table 3.

<u>Table 3.   Mean median RTs and their s.ds. for each GP x VF
combination.   Also shown are the RTs collapsed over VF; B and
R conditions are shown separately.</u>

GP	VF	Blocked		Random	
		Mean	s.d.	Mean	s.d.
1	L	418.75	43.62	425.15	50.01
	R	413.35	44.12	418.00	50.59
2	L	416.90	47.28	421.25	47.77
	R	409.90	40.49	415.40	56.10
3	L	417.20	47.28	430.45	49.27
	R	409.65	48.09	418.20	52.26
4	L	412.05	53.67	415.90	52.50
	R	401.05	51.63	420.00	52.26
5	L	419.65	45.29	425.65	51.80
	R	417.95	46.96	421.65	52.65
		Combined VFs			
1		416.05	42.79	421.57	49.10
2		413.40	42.99	418.32	50.80
3		413.42	46.58	424.32	49.83
4		406.55	51.56	417.95	51.03
5		418.80	44.91	423.65	50.88

Across the horizontal GPs the R condition appeared to produce
a GP x VF interaction that resembled the one found in

Experiment 1, that is, contralateral retardation over the outer GP2 and GP4. At the same time, the LVF was also markedly retarded on the central GP3 compared to the other GPs. In contrast, under B conditions, both VFs had shorter RTs for GP4 compared to GP2 and GP3 which had very similar RTs.

Planned comparisons were made over the vertical and horizontal GPs using three-way (Condition x GP x VF) ANOVAs. These showed that across the horizontal GPs the GP main effect, $F(2,18)=3.01$, $p<0.08$, and the VF main effect, $F(1,9)=4.45$, $p<0.07$, approached significance. Over the vertical GPs the VF main effect, $F(1,9)=3.86$, $p<0.08$, and GP x VF interaction, $F(2,18)=3.20$, $p<0.07$, also approached significance (Appendix E2: Table 4). Importantly, there were no effects involving Condition. So the main prediction, that blocking the trials onto each VDU in turn would enhance any GP x VF interaction, was not supported.

Since Condition produced no significant effects, the data were collapsed over Condition and a final two-way, GP x VF, ANOVA was carried out for the same planned comparisons. Mean medians are shown in Table 4 below where it can be seen that there is a consistent RVF advantage.

There were no significant effects although there were some strong trends (Appendix E2: Table 5). The VF main effect for both the horizontal GPs, $F(1,9)=4.45$, $p<0.07$, and the

Table 4. Mean median RTs for each GP averaged over Condition for each VF. Also shown are the RTs collapsed over VF.

	LVF		RVF		Combined VF	
GP	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	421.95	45.79	415.67	46.26	418.81	45.54
2	419.07	46.31	412.65	47.70	415.86	46.52
3	423.82	47.48	413.92	49.07	418.87	47.92
4	413.97	51.71	410.52	51.49	412.25	50.96
5	422.65	47.46	419.80	48.59	421.22	47.43

vertical GPs, $F(1,9)=3.86$, $p<0.08$, reflecting the RVF advantage. The horizontal GP main effect approached significance, $F(2,18)=3.01$, $p<0.08$, and was due to the RTs for GP4 being faster than for the other two GPs (GP2=416 msec, GP3=418 msec, GP4=412 msec), w^2 accounting for 7.1% of the horizontal experimental variance (1.3% of the horizontal total variance). Across the vertical GPs the GP x VF interaction approached significance, $F(2,18)=3.20$, $p=0.07$; w^2 accounted for 2.2% of the vertical experimental variance. This interaction was due to the RVF being rather slower in the bottom position compared to the top and centre positions (Table 4). The LVF differed by only two msec over the three positions.

As a check on the source of the GP and GP x VF trends, simple main effects were examined for the two conditions separately (Appendix E2: Table 6). There were no significant (or near

significant) effects in the B condition for either vertical or horizontal GPs although the GP main effect accounted for 8% of the horizontal experimental variance. In the R condition, however, the horizontal GP x VF interaction approached significance, $F(2,18)=3.19$, $p=0.07$; w^2 accounted for 10% of the experimental variance (1.8% of total variance). The vertical GP x VF interaction also approached significance, $F(2,18)=3.31$, $p=0.06$, with w^2 accounting for 8.3% of the experimental variance (0.7% of total variance). The vertical VF simple main effect reached significance, $F(1,9)=8.42$, $p<0.02$. Thus, any effect of Condition was shown primarily in the R rather than the B condition, which was contrary to expectations.

The results of this experiment were similar to the first one in giving no support to any of the hypotheses derived from the attentional gradient model. Moreover, there was only a partial replication of the results of the first experiment and of Andreasen (1988), this being the non-significant horizontal GP x VF interaction found in the R conditions. There was considerable variability among the BRRB sessions but a fairly steady increase in RT from the first to the fourth session occurred for the RBBR sessions. This variability may well have obscured any small effects arising from the experimental manipulations. It was therefore decided that practical considerations outweighed statistical niceties of counterbalancing between and within subjects.

Hence, Experiment 3 used two groups of subjects, one receiving R trials, the other receiving B trials.

Experiment 3

Method

The first two experiments required the subjects to make a simple letter identification. This is possibly the simplest task that requires a putative primarily left cerebral hemisphere engagement (Sergent, 1983). The third experiment was used to explore the effects of a more difficult verbal task appropriate to a presumed left cerebral hemisphere engagement. A lexical decision task was chosen for this purpose. Also it was earlier argued in the Introduction that CVF presentation may provide valuable information on a number of substantive issues. For, if CVF performance differs from both divided field performances as GP varies then serious problems arise, not only for Kinsbourne's models, but also for the idea of functional cerebral laterality. Hence, it was decided to include the CVF condition with the LVF and RVF conditions, increasing the number of trials by 260. This increased demand upon the subjects gave added justification for changing to a between-groups design.

Subjects Twenty four subjects,10 males and 14 females aged from 20-39 years, recruited from undergraduate psychology classes, participated in the experiment. All satisfied the

physical requirements of Experiment 1 and each was paid $40 for taking part. Twelve subjects were randomly assigned to each of the two conditions; two subjects were subsequently discarded from the R condition, one due to illness, the other because of mechanical failure.

Stimuli A list of published word norms (Toglia & Battig, 1978) were used to chose a set of 49 three-letter English words. All words were chosen for high familiarity together with low imagery and low concreteness. All words scored 6.0 or higher on the familiarity scale and 3.5 or lower on the imagery and concreteness scales. The list was repeated eight times to produce a pool of 392 words; two words were dropped to give a final total of 390 word stimuli. This pool was randomized and entered into the computer memory. A further list of 49 pronounceable three-letter non-words was prepared with the frequency of first letter incidence being approximately equal to that in the real word list. The list was culled of real word homonyms, familiar acronyms and any other potentially confusing properties. The final list of 390 non-word stimuli was produced in a similar manner to the word stimuli and entered into the computer memory. At the beginning of each session the computer formed each list into a loop and selected a random starting point within each loop. The trial by trial stimuli were then selected randomly from each list until each had been exhausted, the sole restriction being that not more than three successive stimuli came from the one list. Replacement trials were obtained by continuing

through the list for a second time. All subjects received the contents of each list in the same order but usually beginning at different points within them. The full lists of stimuli can be seen in Appendix 2.

Preliminary trials revealed that subjects had difficulty when the stimuli were centred at three degrees eccentricity and 50 msec exposure duration. Therefore, the eccentricity was reduced and the aspect ratio (height:width) of the letters changed from 1:1 to 1:0.5. The stimuli then subtended a visual angle of 1.5 degrees centred 2.5 degrees from the fixation point, the leading edge being 1.75 degrees from the fixation point. This was found to be acceptable and well within the parameters that are ordinarily used with this type of stimulus (e.g., Sergent & Hellige, 1986).

Procedure The procedure was essentially the same as for the previous experiment except that each group of subjects served under only one presentation condition. Stimuli and response fingers were counterbalanced for each subject between the two sessions.

Results and Discussion

After culling null responses, an error rate of 10.5 % (s.d. =2.7) was found but visual inspection revealed no obvious pattern to the errors. The error rate was higher than had been found in the first two experiments and was possibly due to the increased difficulty of the task.

Individual median RTs were extracted for each of the 60 Condition x GP x VF x Stimulus combinations averaged over sessions (Appendix E3: Table 1). These median RTs were then entered into a four way ANOVA with Condition (having unequal 10,12, cell entries) as the between-subjects factor and GP, VF and Stimulus as the within-subjects factors. There were no significant effects involving Condition (Appendix E3: Table 2). The Dunnett test was applied to all stimulus effects other than the main effect which was expected to be significant (e.g., Chiarello, Senehi, & Soulier, 1986). Also, because there was a possibility that the CVF might differ from the other two VFs, the *alpha* level of 0.05 was apportioned at 0.03 for the VF x Stimulus interaction and at 0.004 for the remaining six possible interactions. The expected Stimulus main effect occurred, $F(1,20)=67.97$, $p<0.0001$, Words being faster than Non-words (491 msec *vs* 531 msec); comparable main effects were found in all subsequent analyses where Stimulus was a factor. A significant VF x Stimulus interaction, $F(2,40)=6.79$, $p<0.005$, was found. Analytical analyses (Appendix E3: Table 3) showed that the Stimulus x VF interaction was due entirely to the CVF. There was no evidence for any Stimulus interaction with divided field presentation (Appendix E3: Table 6).

At this point, since no effect of Condition had been found, the data were combined over B and R Conditions and reana-lysed as horizontal and vertical GP planned comparisons. Because the main interest of the research programme derived

from the presumed functional asymmetry of the two cerebral hemispheres, the divided field and CVF conditions were initially analyzed separately.

For the CVF over the horizontal GPs, collapsed over Condition, RTs for words were about 10 msec faster in GP4 than in the other two GPs. RTs for non-words were noticeably slower in GP3 than the two peripheral GPs. Over the vertical GPs, RTs for both classes of stimuli were slower in GP3 than either GP1 or GP5 (Table 5 below).

When the CVF data were entered into the planned comparisons, the horizontal GPs gave a significant GP main effect, $F(2,42)=9.56$, $p<0.0005$, and a significant GP x Stimulus interaction, $F(2,42)=4.20$, $p<0.03$. The GP main effect was found to account for only 1.7% of the horizontal CVF experimental variance with the interaction contributing a further meagre 1%. Across the vertical GPs the GP main effect approached significance, $F(2,42)=3.01$, $p<0.06$; w^2 accounting for 0.7% of the experimental variance (Appendix E3: Table 4).

Analytic one-way ANOVAs showed that for Words, GP4 was significantly faster than the mean of GP2 and GP3, $F(1,21)=4.43$, $p<0.05$, but for non-words, GP3 RTs were slower than the mean of GP2 and GP4, $F(1,21)=19.22$, $p<0.0002$ (Appendix E3: Table 5).

Table 5. CVF mean median RTs (msec) for Words (W) and Non-words (NW) as a function of GP. RTs are shown for both R and B conditions separately and combined.

		Blocked		Random		Overall	
GP	ST	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	W	470.25	22.17	460.66	48.82	465.02	38.51
	NW	515.70	55.81	515.75	26.56	515.72	43.98
2	W	466.75	42.92	474.15	22.08	470.11	34.47
	NW	508.20	40.67	504.10	22.84	506.34	33.08
3	W	470.83	53.74	473.90	19.91	472.22	41.06
	NW	522.95	43.10	522.00	21.30	522.52	34.17
4	W	465.40	15.74	461.91	47.09	463.50	35.66
	NW	508.91	42.53	517.95	26.09	513.02	35.51
5	W	465.37	49.40	465.45	26.41	465.40	39.72
	NW	516.16	45.30	522.00	22.24	518.81	36.00

In the corresponding analysis for the divided VFs, planned comparisons with Stimulus as a factor gave no Stimulus interactions (Appendix E3: Table 6). Accordingly, the divided field data were collapsed across both Stimulus and Condition. Mean median RTs are shown in Table 6 below. Although no statistically significant effects due to Condition had earlier been found, the RTs of Table 6 under B conditions appear to show a small GP effect over the horizontal GPs. There, the RTs for both VFs are faster in GP4 than in the other two positions. Under R conditions a

Table 6. Mean median RTs (msec) and s.ds. for LVF and RVF collapsed over stimuli as a function of GP. RTs for R and B conditions are shown separately and also collapsed over condition and VF.

GP	VF	Blocked		Random		Overall	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
1	L	518.29	51.35	533.47	35.40	523.49	42.73
	R	518.77	53.42	525.42	23.99		
2	L	522.29	43.86	533.75	32.62	521.97	39.05
	R	513.50	48.18	519.97	27.91		
3	L	522.12	48.96	533.75	30.43	524.00	39.11
	R	516.06	45.09	526.05	27.63		
4	L	511.18	46.35	530.67	23.72	516.89	38.02
	R	507.29	45.51	521.47	28.01		
5	L	512.95	40.14	534.17	30.00	520.10	37.00
	R	516.54	46.49	518.97	26.86		

suggestion of a GP x VF interaction may be discerned, similar in nature to those found in the first two experiments. Over the vertical GPs there are no noticeable differences. When the data are collapsed over condition, the horizontal GP main effect becomes much more evident.

Planned comparisons across the horizontal GPs revealed a significant effect for VF, $F(1,21)=10.69$, $p<0.005$, the RVF having an eight msec advantage over the LVF (517 *vs* 525 msec). There was also a significant GP main effect, $F(2,42)=4.69$, $p<0.02$ (Appendix E3: Table 7). w^2 accounted

for a relatively large 13% of the horizontal experimental
variance (4.6% of the total horizontal variance). There were
no significant effects, not even for VF, among the vertical
GPs. When an analysis for simple main effects was carried
out, the source of the horizontal GP main effect was found to
be due to the B condition, $F(2,22)=3.84$, $p<0.05$, with w^2
accounting for 22% of the B experimental variance compared to
3.3% in the R condition (Appendix E3: Table 8).

The inclusion of CVF presentation was to allow a comparison
between a situation where both hemispheres had equal access
to the stimulus with one where only one hemisphere had the
initial access. Accordingly, the data from the horizontal
GPs were reanalysed comparing the CVF with the mean of the
divided fields. Because Stimulus interactions had been found
to occur with CVF presentation, Stimulus was initially
included as a factor.

The horizontal VF x Stimulus, $F(1,21)=6.41$, $p<0.02$, and GP x
VF x Stimulus, $F(2,42)=9.34$, $p<0.0001$, interactions were
significant (Appendix E3: Table 9). However, w^2 accounted
for only 1.1% and 0.5% respectively of the experimental
variance. Across the vertical GPs the VF x Stimulus
interaction was also significant, $F(1,21)=13.03$, $p<0.002$, but
with w^2 accounting for just 2.6% of the experimental variance
compared with 18.2% for the Stimulus main effect. However,
as might be expected from the earlier analyses of the
separate CVF and divided VF data, analytical comparisons

showed that these interactions, both vertical and horizontal, were due solely to the CVF. The low w^2 values, together with the fact that the interactions were due solely to the CVF seemed to be sufficient justification to recompare the mean of the LVF and RVF with the CVF after collapsing over stimuli. Mean RTs for the CVF and also RTs averaged over the LVF and RVF are shown in Table 7.

Table 7. Mean RTs (msec) collapsed over word and non-word stimuli for CVF (C) and the average of the LVF and RVF (L/R) as a function of GP.

GP	VF	Mean	s.d.
1	L/R	523.49	42.72
	C	490.37	36.66
2	L/R	521.97	39.05
	C	488.22	31.78
3	L/R	524.00	39.10
	C	497.37	35.58
4	L/R	516.89	38.02
	C	488.26	32.37
5	L/R	520.12	36.99
	C	492.11	34.66

Table 7 shows that the mean L/RVF RTs were speeded in GP4 compared to all other GPs, but the CVF RTs were retarded in GP3 compared to all other GPs. Across the horizontal GPs all effects reached significance; GP, $F(2,42)=8.44$, $p<0.001$; VF,

F(1,21)=116.51, p<0.0001; GP x VF interaction, F(2,42)=4.00, p<0.03 (Appendix E3: Table 10). The percentage of experimental variance accounted for by each of these was 2.4%, 91.7% and 0.5% respectively.

Over the vertical GPs, only the VF main effect was significant, $F(1,21)=113.06$, $p<0.0001$ with w^2 accounting for 93% of the experimental variance. The high w^2 values for the VF main effect were due to the CVF RTs being some 30 msec faster overall than those of the mean of the LVF and RVF.

The results of this experiment were similar to the earlier ones in the failure to find any support for Kinsbourne's models. The predicted horizontal GP x VF interaction did not appear; instead, an unexpected GP main effect was found. However, this effect appeared under only B conditions and was similar to the non-significant RT pattern found in the B conditions of Experiment 2. It was predicted that B conditions would enhance the GP x VF interaction that was expected under R conditions. Therefore, finding that the interaction has been replaced by a GP main effect cannot be taken as support for Kinsbourne. Indeed, this GP effect goes beyond a simple failure to support the model and provides some evidence against it. This arises because, whereas the interactions found in Experiments 1 and 2 indicated that the two cerebral hemispheres behaved symmetrically under R conditions, the GP effect shows that they act asymmetrically under B conditions.

When the stimuli are presented to the CVF, task performance appears to differ compared to divided VF presentation in two respects. Firstly, GP interacts with the nature of the stimuli when presented to the CVF but not when presented to the LVF or RVF. Secondly, whereas the LVF and RVF RTs are speeded when subjects look to the right (GP4), looking away from the centre (GP3) uniformly results in faster RTs with CVF presentation. One might expect that, if the CVF performance was the resultant of the LVF and RVF processes, then the faster hemisphere should dominate at the appropriate GP. But, the divided VFs differed only in absolute RT across the GPs and the performance of both changed only on GP4, contrasting with the CVF RTs. This indicates that the interaction between the cerebral hemispheres is more complex than Kinsbourne's models presume. The difference between CVF and L/RVF performance will be further considered in the General Discussion section.

Experiment 4

Method

The first three experiments tested Kinsbourne's models using stimuli that required mainly verbal processing. The next two experiments served to extend this testing to tasks that involved mainly visual-spatial processing. In the Introduction, the possibility was raised that predominately verbal processing might produce differing GP effects compared

to mainly visual-spatial processing. Kinsbourne's models are predicated on the notion of functional cerebral laterality, and while the earlier experiments produced no support for his models, some GP and GP x VF effects and trends were found. These effects and trends were contrary to those predicted from Kinsbourne and there was some interest in what effects, if any, would be found for visual-spatial processing which is putatively a right hemisphere function. If the same effects were to be found then clearly, visual-spatial and verbal processing modes do not interact with GP. On the other hand, finding different GP effects would show that GP and processing modality do interact. Additionally, by using tasks of differing complexity, as was done for the verbal tasks, the effect of task difficulty was further investigated.

Subjects Twenty subjects, eight males and twelve females, with an age range from 18 to 28 years, were recruited from undergraduate psychology classes. All satisfied the physical requirements of Experiment 1 and each was paid $40 for taking part.

Stimuli and procedure The subjects were assigned randomly to the R and B conditions; by chance, each condition used four males and six females. The two conditions were run separately. Each subject attended for two sessions of about two and a half hours duration on successive mornings. Filled rectangles, 1.0 cm x 0.3 cm were used as stimuli. The

rectangles could be presented horizontally or vertically, and subjects were required to decide which orientation had been presented during the trial. The retinal eccentricity was three degrees as used in the first two experiments. Otherwise the procedure was essentially the same as that used for Experiment 3, with the two conditions being presented to different groups. In addition to appearing in either the LVF or RVF, the stimuli could also appear at the fixation point (CVF), giving a total of 780 trials per session.

Results and Discussion

Prior to analysis, individual raw RTs were culled for null responses. The overall mean error rate was 4.9% (s.d.=2.0) with no noticeable systematic distribution across conditions. The 1ndividual mean median RTs can be found in Appendix E4: Table 1.

To check on the equivalence of the two stimuli, an initial four-way ANOVA with Condition as the between-groups factor and GP,VF and Stimulus as within-subjects factors was carried out (Appendix E4: Table 2). The Dunnet test was applied to all seven Stimulus interactions with *alpha* apportioned at a (nominal) 0.01 for each interaction. There were other significant effects but only those involving Stimulus are considered at this point. A main effect for Stimulus was found, $F(1,18)=6.09$, $p<0.03$, and was due to the mean RT for the vertical stimulus (363.85 msec) being faster than the RT for the horizontal stimulus (370.91 msec). Although both the

Condition x Stimulus, F(1,18)=4.32, and the VF x Stimulus, F(2,36)=3.62, interactions reached the conventional *alpha* level of 0.05, they fell sufficiently short of the apportioned level to be rejected entirely[8].

There being no significant Stimulus interactions, the data were then collapsed over stimuli and reanalysed using planned comparisons across the vertical and horizontal GPs. Again, the analyses were done separately for the CVF and the divided fields. Group mean medians for the collapsed data are shown in Tables 8, 9, and 10 below.

Table 8. CVF mean medians collapsed over stimuli as a function of GP. Blocked and Random conditions are shown separately and combined.

	Blocked		Random		Combined	
GP	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	370.57	31.03	349.40	24.55	360.27	29.32
2	373.30	25.79	349.52	23.18	361.41	26.80
3	370.20	34.99	350.67	23.75	360.43	30.78
4	375.90	33.84	351.35	22.50	363.62	30.67
5	372.72	29.04	347.82	25.04	359.98	29.32

With Condition as the between-subjects factor and with GP and VF as within-subjects factors there were no significant

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[8]The interactions were almost entirely due to the CVF in the R condition.

effects involving Condition for the CVF, although the main effect for Condition across the horizontal GPs approached significance, $F(1,18)=3.53$, $p<0.08$ (Appendix E4: Table 4). For the divided VFs there were no effects at all involving Condition (Appendix E4: Table 5). The absence of any effects for Condition is rather surprising, since for every GP x VF combination, R condition RTs were faster than B condition RTs (Tables 8, 9, & 10). However, since Condition did not interact with either GP or VF, the groups were collapsed over Condition for all further analyses. These consisted of a similar set of planned comparisons taken over the vertical and horizontal GPs.

The CVF mean median RTs, collapsed over conditions, were essentially the same for all positions, having a range of only 4 msec (Table 8, right panel). The analysis revealed no significant effects for GP (Appendix E4: Table 6); Similarly, the divided field mean median RTs differed little among the various GPs, regardless of condition or VF (Tables 9 & 10, below).

However, the ANOVA for the divided field condition produced a VF main effect that was highly significant for both horizontal, $F(1,19)=25.09$, $p<0.0001$, and vertical GPs, $F(1,19)=26.96$, $p<0.0001$ (Appendix E4: Table 7). The overall mean median RTs collapsed over all five GPs were 376 msec (LVF) and 365 msec (RVF). There were no other significant effects.

Table 9. Mean median RTs (msec) collapsed over LVF and RVF,
and stimuli as a function of GP. Blocked and Random
conditions are shown separately and combined.

GP	Blocked		Random		Combined	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	375.82	31.70	368.30	27.40	368.48	29.80
2	375.13	30.03	365.31	27.08	370.22	28.66
3	373.23	29.16	366.51	29.15	369.87	28.98
4	378.81	37.73	364.78	25.77	371.80	32.67
5	372.91	30.69	364.06	28.97	372.06	29.49

While an overall LVF advantage might have been expected for
geometric stimuli, the RVF advantage that was found may not
be much of an oddity since very simple stimuli often produce
unstable VF advantages (Young & Ratcliffe, 1983). Also,
possible overlearning of the task may have produced a shift
from a visual strategy to a faster verbal strategy (Lempert &
Kinsbourne, 1982) thus giving an RVF advantage. However, an
analysis of the first and second halves of the R condition[9]
showed that the RVF advantage was consistent throughout the
experiment. At the same time, because the subjects were well
practised beforehand, it cannot be ruled out that the
practice period produced a change in strategy.

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[9] Split half analyses of B conditions were subject to
intractable difficulties. This point will be considered in
Problems, Difficulties and Mistakes.

Table 10. LVF and RVF mean median RTs (msec) collapsed over
stimuli as a function of GP. Blocked and Random conditions
are shown separately and combined.

GP	VF	Blocked		Random		Combined	
		Mean	s.d.	Mean	s.d.	Mean	s.d.
1	L	381.60	32.20	374.85	29.37	375.33	34.24
	R	370.05	31.77	361.75	25.05	361.63	23.48
2	L	375.97	30.28	370.77	29.59	373.37	29.26
	R	374.30	31.40	359.85	24.63	367.07	28.45
3	L	378.70	28.18	375.07	32.65	376.88	29.74
	R	367.77	30.57	357.95	23.76	362.86	27.12
4	L	384.95	42.19	368.77	26.52	376.86	35.29
	R	372.67	33.80	360.80	25.75	366.73	29.87
5	L	381.00	34.96	369.67	34.38	378.22	30.20
	R	364.82	24.92	358.45	22.81	365.90	28.17

For the fourth successive experiment, no support was found
for Kinsbourne's models. The predicted GP x VF interaction
indicating contralateral facilitation did not appear. In the
absence of this interaction, the enhancement that was
expected for B conditions might reasonably have shown itself
by shorter RTs. But the shorter RTs were found under R
conditions. At the same time, the GP x VF interaction that
was found under R conditions in the first two experiments and
the GP effect that was found under B conditions in Experiment
3 did not reappear.

Other than the stimulus main effect, which was irrelevant to the investigation, and the overall faster RTs under R conditions, there were no experimental effects at all. This suggests that either GP effects are shown only when verbal stimuli are used, or the stimuli were too simple to reveal any effects. If the first suggestion proved to be correct, then these results seem to give some support to the notion that whether or not GP affects performance depends to some degree on the stimulus-task combination. On the other hand, the very simplicity of the stimulus-task combination may have been the determining factor, in which case a combination of greater complexity than the lexical decision of Experiment 3 should show stronger effects. Since an investigation of the effects of task difficulty was one component of this research programme, a stimulus-task combination that seemed, intuitively, to be more complex than a lexical decision was chosen for the fifth experiment.

Another of the original intentions of the research programme was to compare R and B conditions across a variety of tasks. However, with three successive experiments producing only elusive differences between R and B conditions, a continuation of this comparison was thought not to be worthwhile. It was decided, therefore, that a comparison between alternative methods of obtaining overt attention would be more useful. Kinsbourne (1972) regards eye and head turning as being equivalent; that is, he presumes that turning the eyes in the head is equivalent to turning the head in order

to look to a particular part of the external visual field, but this presumption has never been tested. Furthermore, the only experiments involving both head and eye turning to have been carried out (Kinsbourne, 1975; Lempert & Kinsbourne, 1982) completely confounded the two movements. Hence, the programme was altered to test this aspect of Kinsbourne's models by comparing head turning with eye turning. Since the GP x VF interaction under R conditions (including Andreasen, 1988) had been the more consistent of the GP effects, trials were presented under R conditions while having one group use eye movements alone with the other group using head turning alone in order to direct attention to the different GPs.

Experiment 5

Method

Subjects Twenty subjects (10 males and 10 females) recruited from undergraduate psychology classes participated; the age range was from 18 yrs to 25 yrs. All satisfied the physical requirements of Experiment 1 and were paid $40 each for taking part. All were pretested for their ability to do the task and a number of potential subjects were rejected at this stage. Subjects were assigned randomly to randomized eye (RE) movement and randomized head (RH) movement conditions, with the two conditions being run as separate experiments. By chance, each condition used five male and five female subjects. Each subject attended for two sessions of about two and a half hours duration on successive mornings.

Stimuli and procedure The stimulus was a cartoon face having only one ear. The subject's task was to decide which ear, right or left, was present. Each of the two alternatives could appear in one of four configurations. Upright and facing the subject, upright and facing away, inverted and facing, and inverted and facing away, yielding a total of eight possible selections. The face was based upon a 2 cm square, the hair and the ear (a small filled rectangle) being outside the square; the eyes were small circles and the mouth a shallow 'V'. Stimuli presented to the LVF or RVF were centred at a three degree retinal eccentricity. Stimuli presented to the CVF had the square that formed the outline of the head centred at the fixation point. A handed set of stimuli are shown in Figure 5. Preliminary tests showed that a stimulus exposure time of 100 msec was needed to obtain an acceptably low error rate. All of the eight possible options appeared four times in each of the 15 GP x VF conditions giving a total of 480 trials per session.
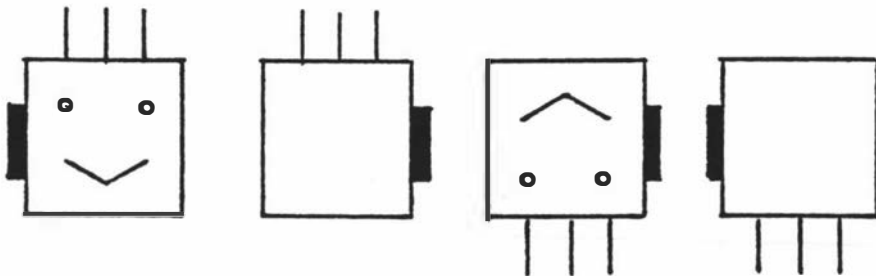
Figure 5. Right eared set of stimuli used in Experiment 5.

The procedure for the RE condition was the same as for the R condition of Experiment 4, trials being self paced. For the RH condition, the stimulus presentation and responding was as for the RE group. However, the bite bar was removed and the subjects were told to turn their heads to face the presentation VDU for every trial. It was emphasised that they must be facing the appropriate VDU squarely with their eyes centred in their heads. They were frequently reminded to do this and the experimenter monitored them by watching their silhouettes against the low luminance apertures in the equipment. The subjects were asked to use the equipment framework as a guide to maintaining correct head location. As before, each subject's stimulus and response finger pairings were counterbalanced between sessions.

Results and Discussion

As usual, the individual raw RTs were culled for null trials and errors; a mean error rate of 5.8% (s.d.=3.2) was found. Errors were spread evenly over all conditions.

Intuitively, it was suspected that the inverted stimulus versions would provide the more difficult task, a suspicion that was supported by subjects' comments. It was decided, therefore, to treat the erect and inverted stimuli as separate classes, as was done for words and non-words in the third experiment. Although there was no reason to believe that left and right eared stimuli would produce differing performances, forward or back facing stimuli may have done

so. However, even if the right and left eared versions of a particular stimulus were to be treated as a combined distribution, there would only be eight trials per session from which to derive an estimate of the median. This was too small a number to give a stable estimate of the median (Miller, 1988) so all of the erect stimuli, and all of the inverted stimuli were treated as two distributions for the purpose of obtaining an estimate of the medians. Accordingly, the RTs within the erect and inverted stimuli were combined to give individual overall median RTs, each based on 16 trials, for the 30 GP x VF x Stimulus (erect/inverted) combinations.

The individual mean median RTs (Appendix E5: Table 1) were entered into a four way mixed ANOVA with Condition(2: eye *vs* head turning) as the between-subjects factor and GP(5), VF(3) and Stimulus(2) as the within-subjects factors. There were no significant effects involving Condition and the only Stimulus effect to reach significance was the main effect, $F(1,18)=84.75$, $p<0.0001$ (Appendix E5: Table 2). A significant VF main effect, $F(2,36)=23.46$, $p<0.0001$ which was due to the CVF having shorter RTs than those for the LVF and RVF, was found. The GP main effect was also significant, $F(4,72)=3.38$, $p<0.02$, and appeared to be due to the mean median RTs being speeded over the vertical GPs from GP1 to GP5. The subsequent main analysis confirmed the source of the GP and VF effects.

With no interactions involving Condition or Stimulus, the analysis proceeded with the subjects being combined into one large (N=20) group with the data collapsed over Stimulus. The CVF and divided VF were analyzed separately. Mean median RTs collapsed over Stimulus for the CVF can be seen in Table 11 below.

Taking into consideration the relatively large s.ds, RTs for the CVF differed little over the GPs. The only difference found for the CVF was a marginally significant GP effect, $F(2,38)=3.1$, $p<0.06$, over the vertical GPs (Appendix E5: Table 3), w^2 accounting for 17.3% of the experimental variance. The effect was due to GP5 having shorter RTs than GP1 and GP3.

Table 11. CVF mean median RTs (msec) collapsed over stimuli as a function of GP. Eye movement and Head turning conditions are shown separately and combined.

GP	Eye movement		Head movement		Combined	
	Mean	s.d.	Mean	s.d.	Mean	s.d
1	814.95	167.37	793.97	167.57	804.46	165.65
2	784.72	165.53	792.92	167.57	788.82	164.46
3	819.22	174.82	788.77	174.42	804.00	173.06
4	787.02	162.53	796.82	150.50	791.92	154.69
5	789.27	163.87	774.65	145.62	781.96	153.19

The mean median RTs for the divided VFs are shown in Table 12. Like the CVF, the only noticeable differences among the divided field RTs was that both LVF and RVF generally showed a steady speeding from GP1 to GP5 (right panel) but this GP main effect was not significant, $F(2,38)=2.52$, $p<0.09$, (Appendix E5: Table 4).

The CVF and divided field results, being so similar, were entered into a single analysis (Appendix E5: Table 5). There was a significant GP effect over the vertical GPs, $F(2,38)=6.45$, $p<0.005$, due to a steady speeding of RTs from

Table 12. LVF and RVF mean median RTs (msec) collapsed over stimuli as a function of GP. Eye movement and Head turning conditions are shown separately and combined.

GP	VF	Eye movement Mean	s.d.	Head movement Mean	s.d.	Combined Mean	s.d.
1	L	835.17	159.81	839.30	193.89	837.23	175.39
	R	830.15	178.85	834.87	173.00	832.51	173.70
2	L	813.02	153.03	821.45	174.36	817.23	161.98
	R	810.15	177.15	824.02	169.59	817.08	171.32
3	L	825.30	170.65	818.75	175.31	822.02	170.79
	R	831.42	165.99	832.80	165.41	832.11	163.57
4	L	814.90	172.51	832.92	168.20	823.91	168.42
	R	836.30	152.28	805.02	154.15	820.66	152.07
5	L	796.82	149.81	819.72	156.42	808.27	151.62
	R	820.50	149.55	837.10	181.40	828.80	164.31

GP1 to GP5 (Table 13 below). w^2 for this GP effect accounted for 12.6% of the experimental vertical variance. A significant VF main effect was found, for both the horizontal GPs, $F(2,38)=12.42$, $p<0.0001$, and the vertical GPs, GPs, $F(2,38)=16.08$, $p<0.0001$. Both effects appeared to be due to the RTs being faster in the CVF than in the LVF and RVF, mean RTs being 794.24, 821.74 and 826.24 msec

Table 13. Mean median RTs (msec) collapsed over VF and stimuli as a function of GP. Eye movement and Head turning conditions are shown separately and combined.

GP	Eye movement		Head movement		Combined	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	826.75	166.20	822.71	176.67	824.73	170.80
2	802.63	163.21	812.80	168.21	807.71	165.11
3	825.31	167.69	813.44	169.85	819.37	168.17
4	812.74	161.16	811.59	155.89	812.16	157.88
5	802.20	152.50	810.49	161.27	806.34	156.34

respectively. This interpretation was confirmed by comparing the CVF to the mean of the divided fields. A significant VF main effect appeared for both the horizontal GPs, $F(1,19)=16.58$, $p<0.001$, and the vertical GPs, $F(1,19)=23.18$, $p<0.0001$ (Appendix E5: Table 6).

The failure to find any GP x VF interactions for the divided VFs across the horizontal GPs certainly supports the notion that eye and head turning are equivalent. However, this

equivalency is in terms of a *lack* of effects and equating the two conditions is a rather strong assertion requiring more support than merely accepting the null hypothesis. Inspection of the cell entries (Table 12) shows that, to some extent, the RTs for the divided fields appear to be consistent with GP x VF interactions over the horizontal GPs. The interaction under RE conditions is similar to those found under R conditions for the first three experiments, in that the RVF RTs are speeded from right (GP4) to left (GP2). However, under RH conditions the RTs for the LVF are speeded from right to left with the RTs for the RVF being speeded from left to right. This GP x VF interaction appears to be consistent with the contralateral facilitation that was predicted from Kinsbourne's models. To test the reality of these observations, an analysis for simple main effects was carried out on the horizontal GP data, collapsed over stimuli.

The GP x VF interaction under RE conditions was not significant (F=0.97) despite accounting for 10.9% of the experimental variance. In the RH condition, however, the interaction was significant, $F(2,18)=4.37$, $p<0.03$, accounting for 19.4% of the experimental variance (Appendix E5: Table 7). Analytical comparisons showed that the interaction was due mainly to the RVF which had shorter RTs in GP4 than for the other two GPs, $F(2,18)=6.89$, $p<0.01$; RTs for the LVF did not differ significantly across the GPs (Appendix E5: Table 8). Thus, the suspected GP x VF interactions were more

apparent than real, the only significant effect being due to the RVF in the RH condition

In this, the final experiment of the research programme, there was again little support for Kinsbourne's models. The predicted GP x VF interaction due to contralateral facilitation did not occur. It is true that the interaction found under RH conditions lends some support to the contralateral facilitation hypothesis. However, finding that the RVF RTs were shortest in GP4 is insufficient to provide support for Kinsbourne's models. The models require that *both* VFs show contralateral facilitation, an effect that was not found in this experiment. Also, under RE conditions, RTs from the horizontal GPs conformed more to the ipsilateral facilitation found in earlier experiments, but not significantly so. Hence, Kinsbourne's presumption that eye and head turning have equivalent and significant effects on performance was not borne out.

The possible effect of task complexity was also examined. A GP x VF interaction that had been found on three occasions, when using verbal stimuli, disappeared when using very simple visual stimuli in Experiment 4. It was thought that by using a more complex task-stimulus the interaction might be restored but this did not happen. Since the interaction that did occur was restricted to one VF in the RH condition it is unlikely that it was due to increased task complexity. This is because the effect of increased complexity would be

expected to be shown in the RE condition as well as the RH condition; it would also be expected in both VFs.

The only consistent effect was that RTs in the lower GP5 were generally faster than the upper GP1 and central GP3. Except for the RVF in the RH condition the effect occurred in all VFs, CVF included, in both conditions. The effect was opposite to the vertical GP effect found by Andreasen (1988) and in Experiment 1. But it can be noted that on both of these earlier occasions simple stimuli were used and therefore complexity may have had some effect on performance in Experiment 5.

General Discussion

Experimental programme

Divided field

The major objective of the present experimental programme was to investigate whether or not voluntary eye movements, here called reverse CLEMs, have any instrumental value in cognition. Using a divided field paradigm with RT as the dependant variable ensured, as far as is known, that the bulk of the processing was carried out by the targeted cerebral hemisphere. This allowed the major theoretical accounting of CLEMs (Kinsbourne, 1972) to be tested directly. The account presumes that eye movements are initiated by the selective arousal of one or the other hemispheres, This approach also enabled Kinsbourne's (1970, 1975) attentional gradient model of functional cerebral asymmetry to be tested using a novel methodology. Testing this model extended the relevance of the programme into the general topic of cerebral laterality.

The support that was found relating to these objectives was somewhat elusive, but there was little, if any, support for Kinsbourne's models. The GP x VF interactions that were expected on the basis of his (1972) model did not appear. The effects of GP that did appear were seldom reproducible from one experiment to the other. This inconsistency was possibly due to the fact that, as the low w^2 values indicate, GP appears to produce only a weak effect. With only 10

subjects used in most groups the experiments were statistically underpowered for the effect size (Cohen, 1988). In the wider context of Kinsbourne's (1970, 1975) attentional gradient model, it was expected that when RTs differed between GPs, then the differences would be greater for Blocked than Randomized trials. Four experiments failed to produce any difference between the B and R conditions when each experiment was considered alone. At the same time, however, visual inspection of the R and B condition RT profiles for the various experiments suggested that the two conditions were producing consistent if small effects. Analyses for simple main effects also suggested that there were some differences between the conditions. Although the RT differences between the GPs were too small to appear when the experiments were analyzed separately, when the data were combined into a form of meta analysis consistent differences did emerge; this will be discussed later.

The results of Experiment 1, where the letters X and V were used as stimuli, did not support the prediction made from Kinsbourne (1972, 1973, 1975), namely, that over the horizontal GPs a symmetrical contralateral facilitation of each retinal hemifield would occur giving a horizontal GP x VF interaction. The interaction that was found in this experiment was consistent with ipsilateral facilitation and so was directly contrary to the prediction. Furthermore, the interaction was markedly asymmetric since most of the GP effect occurred in the RVF. Over the vertical GPs, it was

predicted from neuroanatomical considerations (Bender, 1980) that while a GP x VF interaction would not occur, a GP facilitation would appear when the eyes moved vertically away from the central GP. Although the interaction did not appear, neither did the GP facilitation. Instead a trend towards a GP effect was found where RTs were retarded when looking downwards.

GP did affect RTs for a simple letter identification task. The effects were quite small, the RT differences never exceeding eight msec with w^2 accounting for only 3.9% of the horizontal experimental variance.   While contrary to the predictions made from Kinsbourne's theory, the GP x VF interaction observed over the horizontal GPs was similar to the interaction reported by Andreasen (1988). The GP trend over the vertical GPs was also similar to that reported by Andreasen.

In Experiment 2 the letters X and V were again used as stimuli. There were no significant effects although there were some trends that indicated that the R and B conditions interacted differently with GP. These trends provided no support for the predictions made from Kinsbourne's model. However, the trend towards a horizontal GP x VF interaction in the R condition was similar to both Experiment 1 and Andreasen (1988). The elusiveness of the effects is well illustrated by the trend towards a vertical GP x VF interaction which was due to the RTs for the RVF alone being

retarded in GP 5, LVF RTs scarcely varying over the GPs. In fact, none of the remaining experiments produced retarded RTs in the lower GP. One possible reason for the failure to find significant effects is that excessive motivational demands were made of the subjects. Another possible reason is that given the small effect size and with only 10 subjects it is almost certain that the experiment had low statistical power. A consequence of low power is to make it difficult to replicate results, especially when the effect size is small (Cohen, 1988).

Again, in Experiment 3, where a lexical decision task was used, there was no evidence to support any predictions made from Kinsbourne's models. Not only was the expected GP x VF interaction not enhanced in the B condition compared to the R condition, but the interaction itself failed to materialize under either condition. A small GP main effect only was found under B conditions in which RTs in GP4 were some six msec faster than those of GP2 and GP3, whereas RTs from GP2 and GP3 did not differ. This effect was similar in magnitude and direction to the trend found in the B condition of Experiment 2.

Experiment 4 also failed to produce any evidence to support Kinsbourne (1970, 1972, 1975). Just as in Experiment 3, the predicted GP x VF interaction was neither enhanced under B conditions compared to R conditions, nor did it materialize. Furthermore, neither the small GP main effect that was found

in Experiment 3 nor the similar trend found in Experiment 2 reappeared.

Finally, Experiment 5 also failed to support any of the predictions made from Kinsbourne (1970, 1972, 1975). A GP x VF interaction was not found across the horizontal GPs under RE conditions. The GP x VF interaction that was found under RH conditions was due to the RVF alone, having speeded RTs when looking to the right GP. This interaction, while consistent with contralateral facilitation, provides inadequate support for Kinsbourne's models. This is because his models require that contralateral facilitation occurs equally for both VFs. The interaction therefore weighs against Kinsbourne's models on two counts. The effect is restricted to one cerebral hemisphere and it only occurs when the head is turned, not when the eyes move. In other words, head and eye turning are not equivalent. The vertical GP effect that was found could be said to partially fulfil the prediction, made by applying neuroanatomical information (Bender, 1980) to Kinsbourne's models, the prediction being that vertical movements would produce shorter RTs in the deviated GPs. In this case, downward facilitation occurred, but the tendency for upward retardation was contrary to predictions. Kinsbourne's models require that GP effects be symmetrical about the central GP and this second failure to find such symmetry must count against them. Furthermore, the observed effect can readily be accounted for by the joint effects of interference due to muscular fatigue when looking

upward and facilitation when looking downward in the habitual reading position.

These conclusions must be qualified, however, because the cartoon faces that were used as stimuli probably produced complex stimulus-response (S-R) compatibility effects. This can be seen by considering the possible S-R compatibilities when subjects respond to, for example, the right ear on an inverted, forward-looking face. One combination of the experimental variables could be: the RIGHT ear appearing to the RIGHT of the stimulus, in the LVF while the subject looks to the RIGHT GP and responds with the LEFT finger. S-R compatibility is easily confused with laterality effects (Heister & Shroeder-Heister, 1987) and in this case may have masked any experimental effects.

Vertical GPs

When Kinsbourne's arousal model was applied to vertical movements, it was predicted that any deviation away from the central GP3 would lead to speeded RTs. This was because, with vertical movements being bilaterally controlled (Bender, 1980), arousal would be symmetrical between the cerebral hemispheres and hence a GP main effect only was expected. Now, of course, one could invoke intrahemispheric interference and predict that retardation of RTs would be found. The actual data showed that there was no systematic pattern over the experiments. In Experiment 1 a small retardation was found in the bottom GP5 but Experiment 5

produced a rather larger retardation in the top GP1. The remaining experiments also yielded variable results. That there seems to be no consistent relationships among GP, VF and RT may not be too surprising when one considers the neuroanatomy of vertical eye movement control.

To begin, both cerebral hemispheres must be activated for true vertical movement to occur and initiation of movement seems to be originate mainly within the midbrain (Bender, 1980). Thus, bias due to cortical activity would be reduced due to the cortical input being both diffuse and distributed across both halves of the midbrain. Furthermore, if a transverse plane is drawn through the midline of the parts of the brain that control vertical eye movements, pathways dorsal to this plane subserve downward movements while pathways ventral to the plane subserve upward movements. Since the stimuli were always presented on the horizontal median of the retina, there is no reason for gaze direction to produce any bias in the vertical plane. To argue otherwise would imply that a vertical analogue to cerebral laterality occurs which, while not necessarily impossible, is scarcely credible.

CVF

Once some of the major methodological issues had been resolved, CVF presentation was included in the final three experiments. It was hoped that by doing this a number of interesting questions could be answered, such as, did the CVF

performance match one or the other of the divided fields? Alternatively, did it appear to be the resultant of the combined LVF and RVF performances? Or, would there be no apparent relationship between CVF and divided field performance?

In Experiment 3, where words and non-words were used as the stimuli, a GP x Stimulus interaction was found for CVF presentation. This interaction is rather strange especially when a similar interaction did not occur for the divided field condition. Tressoldi (1987) used CVF presentation and reported a GP effect with words and non-words, but no interaction. There seems to be no reason for words and pronounceable non-words to be processed differently when GP is varied. The implication is that words and non-words are processed at different locations in the brain, requiring that they be recognised and redirected to separate locations. This seems unlikely. The interaction is thus unexplained and since it has no apparent bearing on the main issues, it will not be further discussed. This course of action can be further justified by the fact that within the overall variability across the horizontal GPs, the Stimulus x GP interaction accounted for only 0.5% of the experimental variance.

When the Stimulus effect in Experiment 3 was disregarded the CVF did not differ meaningfully from the two divided fields except in terms of overall RT values. Although the

horizontal GP x VF interaction over all three VFs was significant, the effect accounted for only 0.1% of the experimental variance. Thus, it is fair to say that, other than producing faster RTs, the CVF did not differ meaningfully from the two divided fields; nor did the divided fields differ between themselves.

Experiments 4 and 5 likewise showed that CVF presentation gave essentially the same results as for divided field presentation. In Experiment 4 there were no significant effects at all, while in Experiment 5 the only effect was that over the vertical GPs all VFs were speeded from GP1 to GP5.

So, the inclusion of the CVF condition showed that the effect of GP was essentially the same regardless of whether one or both cerebral hemispheres received the stimulus information. The only qualification that can be made is that visual inspection of the various RT cell entries suggests that across the horizontal GPs under R conditions there is a slight tendency for the CVF to match the RVF rather than the LVF.

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Further analysis

</div>

Task Difficulty

When considering the experimental hypotheses stated in the Introduction, a rationale was offered for expecting that task

difficulty would interact with GP and/or VF. The rationale was based on the fact that a number of studies had shown that the extent or frequency of saccades was influenced by the apparent difficulty of the experimental task. It was then suggested that the converse situation, that saccadic extent could interact with task difficulty, might also occur. If this idea had any substance, a Difficulty x GP interaction should be found, and possibly a Difficulty x GP x VF interaction also. Three possibilities were considered. A GP effect could be constant and independent of task performance, it could be constant but interacting multiplicatively with task performance, or it could be proportional to task performance. In the first case, a GP effect would be more evident with the simpler tasks, in the second case the effect should be equally evident over all levels of difficulty. For the third case, the effect should increase with difficulty. RT was taken as an index of difficulty, the rationale being that the more difficult tasks would require a longer time to complete than the easier ones. Thus, the different experiments themselves would serve to define the levels of Difficulty.

Before proceeding to the main analysis, the first two experiments, both of which used the letters "X" and "V" as stimuli, were compared to determine whether or not they could be combined into one large experiment. The individual mean medians from the first two experiments were used with the data from Experiment 2 being collapsed over blocked and

random conditions. The usual procedure of making separate comparisons across the horizontal and vertical GPs was followed. There were no significant (or nearly significant) effects involving Experiment (Appendix Diff: Table 1). Experiments 1 and 2 could therefore be treated as one large experiment (N=20) for the subsequent analysis.

Letting the data from the first two experiments represent one level of difficulty, the data from this combination and all other experiments were then entered into a mixed ANOVA. Experiment (with unequal, 20,22,20,20, cell entries) was the between-subjects factor and GP and VF were the within-subjects factors. The factor, "Experiment", had four levels of difficulty, indexed by RT: Rectangles, Letters, Words, and Faces. As usual, comparisons were made separately over the horizontal and vertical GPs. Because the first two experiments did not have the CVF condition, the overall analysis was restricted to the LVF and RVF.

Across the horizontal GPs there was the expected main effect for Experiment, $F(3,78)=174.19$, $p<0.0001$ (Appendix Diff: Table 2). The RTs for Rectangles, Letters, Words and Faces were 372, 415, 521 and 822 msec respectively supporting the validity of using RT as an operational indicator of difficulty. There was a significant VF main effect, $F(1,78)=12.54$, $p<0.001$. However, there was also a significant Experiment x VF interaction, $F(3,78)=2.91$, $p<0.05$. This was due to Rectangles, Letters and Words all

having RVF advantages of 6 to 8 msec whereas Faces had a (nonsignificant) LVF advantage of 2.3 msec. This simply reflects the fact that experiments using Letters, Rectangles and Words produced significant RVF advantages whereas using Faces did not.

The vertical GPs produced a very similar pattern of effects (Appendix Diff: Table 2). The main effect for Experiment was significant $F(3,78)=166.87$, $p<0.0001$ with RTs of 372, 419, 523 and 827 msec respectively for Rectangles, Letters, Words and Faces. There was a significant VF main effect, $F(1,78)=5.29$, $p<0.03$ together with a significant Experiment x VF interaction, $F(3,78)=6.90$, $p<0.001$. The source of this interaction was the same as that for the horizontal GPs in that Faces gave a small LVF advantage while the other experiments all had RVF advantages. The Experiment x GP interaction approached significance $F(6,156)=2.05$, $p<0.07$, due to the speeding of Experiment 5 RTs from the top GP1 to the bottom GP5 (Table 13; p. 136). However, w^2 for this interaction accounted for a mere 0.05% of the experimental variance.

The presence of a clear Experiment x GP interaction, which is the critical requirement for a difficulty effect, did not occur. While a near significant Experiment x GP interaction was found, it was a very small effect. Also it occurred over the vertical GPs, rather than the horizontal GPs where the largest and most consistent GP effects had been found.

Furthermore, the effect can be adequately explained in terms of acquired reading habits and/or eye muscle fatigue. However, although this analysis provides little, if any, evidence for a difficulty effect, the approach can be criticised on the grounds that difficulty was confounded with the processing of different tasks. There is no guarantee that the failure to find any interactions between GP and Difficulty was due to the absence of a Difficulty effect; it could well be due to the differing processing requirements of the various tasks. It appears, therefore, that before firm conclusions are drawn regarding the possibility of a Difficulty x GP interaction, some means of equalizing the processing requirements at various levels of difficulty will have to be devised.

Meta analysis.

Investigating the possibility that task modality might affect any observed GP effects was one of the objectives of this research programme, but before analyzing the results for modality an alternative treatment of the data was undertaken. The need for an alternative treatment came about because it was noted that under R conditions, the first three experiments tended to produce GP x VF interactions over the horizontal GPs, the interactions being consistent with ipsilateral facilitation. Also, under B conditions and across the horizontal GPs, the second and third experiments tended to produce a GP main effect where RTs in GP4 were shorter than those of GP2 and 3. However, with only small

and elusive effects having been found, increasing the overall statistical power was an attractive option. Therefore, it was decided that, wherever possible, the results of the various experiments would be combined into a form of mini meta analysis.

When RT was plotted against GP to produce RT/GP profiles for the various experiments and conditions it appeared that the R conditions of Experiments 1 and 2 gave similar GP x VF interactions. RT/GP profiles also revealed that the GP effects in the B conditions of the second and third experiments resembled one another. The RT/GP profiles for Experiment 4, however, were similar across conditions and also had a different shape compared to those of the first three experiments. This visual inspection suggested that it might be useful to combine the data according to whether VQAs (Experiments 1, 2 & 3) or SQAs (Experiment 4) were used. Moreover, it also seemed useful to re-examine the data in terms of R and B presentation. Thus, the data from the R conditions of the first three experiments were combined, as was the data from the B conditions of the second and third experiments. Since no effect of Condition was found for Experiment 4, the earlier analysis using combined conditions was considered to be a part of this new analysis. The data from Experiment 5 were excluded because they might have been contaminated by S-R compatibility effects; CVF data were also excluded because they were only available for Experiments 3 and 4.

The data from the first three experiments were combined as indicated above and the resulting RT/GP profiles are plotted in Figure 6. There it can be seen that in the B condition the profiles for both VFs are similar, both showing that RTs in GP4 are faster than for the other two GPs. In contrast, the profiles in the R condition are dissimilar. The LVF profile is similar to those in the B condition whereas
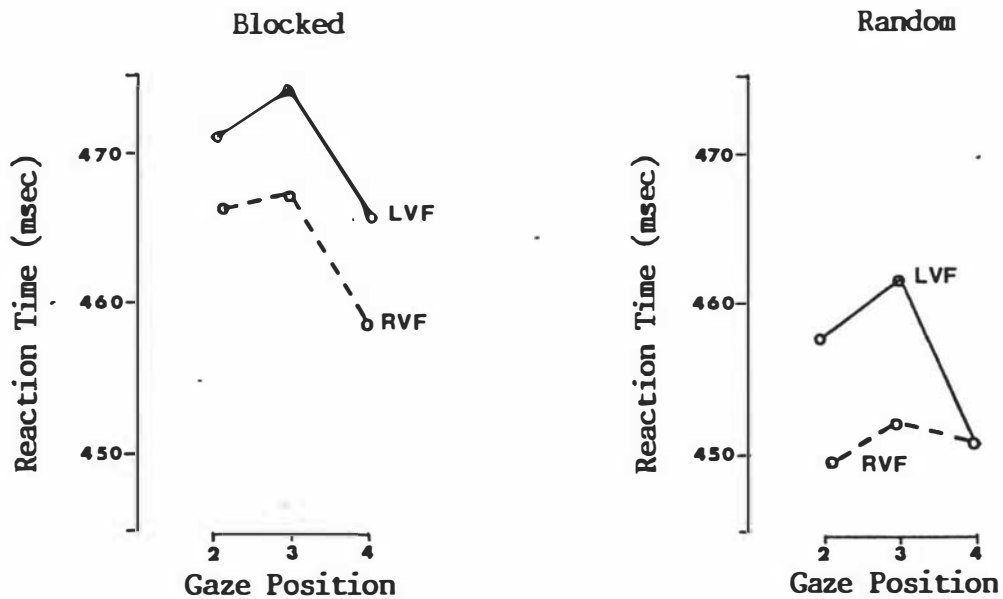
Figure 6. RT profiles across the horizontal GPs for Experiments 1, 2, and 3 combined.

the RVF profile is virtually flat, there being less than 4 msec difference among the GPs. That these profiles give a fair indication of the way GP affects RT is supported by noting the number of subjects who provided the data. The B profiles came from 20 subjects with 30 contributing to the

R profiles. Further support comes from the statistical analysis.

As usual, the analysis took the form of separate planned comparisons for the horizontal and vertical GPs, but in this case horizontal GPs are considered separately from the vertical GPs. (The significant VF main effects are ignored.) In the R condition, the horizontal GPs yielded a GP main effect, $F(2,62)=4.59$, $p<0.02$, and also a GP x VF interaction, $F(2,62)=3.57$, $p<0.05$ (Appendix Meta: Table 1). These effects accounted for 8.6% and 4.7% of the experimental variance respectively. The RT/GP profile (Figure 6, right panel) shows that the major source of these effects was the LVF. In the B condition only the GP main effect was significant, $F(2,42)=5.69$, $p<0.01$ (Appendix Meta: Table 2) accounting for 13.1% of the experimental variance.

As already noted, it is only the RVF that differs between the R and B conditions. In Figure 6 the two RVF profiles differ in the right (GP4) position but the LVF produces essentially the same profile in the two conditions. A *post hoc* analysis was made comparing the RVF data from the B conditions with the RVF data from the R conditions. Condition was the between-subjects factor with GP as the within-subjects factor; the critical effect was the Condition x GP interaction. A similar analysis was done for the LVF data. The results of the analyses showed that while the two RVFs differed, indicated by a significant Condition x GP

interaction, F(2,100)=4.99, p<0.01, the LVFs did not
(Appendix Meta: Table 3).

No consistent GP or GP x VF trends had been found over the
vertical GPs in the earlier analyses and there were no
significant effects when the first three experiments were
combined. The GP x VF interaction did, however, approach
significance in both the R, F(2,62)=2.63, p<0.08 (Appendix
Meta: Table 4), and B conditions, F(2,42)=2.61, p<0.09
(Appendix Meta: Table 5). The similarity of the RT/GP
profiles for the two conditions prompted a further analysis
using the combined R and B data for the vertical GPs. The
combined data from all three experiments yielded a
significant GP x VF interaction, F(2,106)=5.26, p<0.01
(Appendix Meta: Table 6); w^2 accounted for 5.1% of the
experimental variance. The interaction appeared to be due to
the LVF RTs being slightly retarded in GP3 (466.6 msec)
compared to GP1 (464.2 msec) and GP5 (463.2 msec), coupled
with the RVF RTs being faster in GP3 (459.1 msec) than in GP1
(461.1 msec) and GP5 (462.4 msec).

Modality

In contrast to the RT/GP profiles for VQAs (Figure 6), the VF
profiles for Experiment 4, which used rectangles as SQAs,
show a general similarity between the R and B conditions. In
fact, only the RTs from the LVF in GP4 seem to differ between
the two conditions, which, in its turn, appears due to just
one individual median RT being abnormally retarded (Appendix

E4: Table 1). This impression is supported by the ANOVAs for Experiment 4. The earlier analysis showed that there were no effects involving condition (Appendix E4: Table 5) and when the data were collapsed over condition there were no effects involving GP (Appendix E4: Table 6). Other than a VF main effect the LVF and RVF RTs were very similar. When collapsed over conditions, thereby using the data from 20 subjects, neither varied by more than about 4 msec across the GPs (Table 10; p. 128); a 4 msec difference is very little given the relatively large s.ds. Thus, it would appear that GP effects did not occur when SQAs were used as stimuli.

The results of the foregoing extended analysis can be summarized as follows. When VQAs are used as stimuli the effects of varying GP are different for Blocked and Randomized trial presentation. The differing effects in the two conditions are restricted to the horizontal GPs. A small but real horizontal GP effect appears when trials are blocked onto each GP in turn, revealed by RTs being shortened by between five and ten msec when subjects look to the right GP compared to the left or central GPs. However, when trials are randomized among the GPs, a small GP x VF interaction is found over the horizontal GPs. It appears as ipsilateral speeding of the LVF when looking to the right GP and speeding of the RVF when looking to the left GP; the effect being most evident for the LVF. Also, only the RVF appears to differ between the R and B conditions. The interaction is directly contrary to the contralateral interaction predicted by

Kinsbourne's (1972) model. Over the vertical GPs a GP x VF interaction appeared but only when all the data from the first three experiments were combined. This interaction was small in magnitude and was due to the GP3 RTs being slowed for the LVF but speeded for the RVF relative to the other GPs. RTs for the LVF conformed to the predicted facilitation when looking away from the central GP3 but those for the RVF were contrary to the prediction.

The presence of GP effects when VQAs were used as stimuli coupled with the absence of GP effects when SQAs were used suggests that GP interacts selectively with VQAs. Also there was no evidence for an interaction between difficulty and GP. Finally, there was no support to for Kinsbourne's attentional gradient model or his lateral arousal accounting of CLEMs.

Explanations

The small difference in the effects of GP between B and R conditions when using verbal stimuli is intriguing. On the one hand, R conditions produce what would be a crossover interaction but for the usual VF main effect that is found when verbal stimuli are used. This interaction is directly contrary to that predicted by Kinsbourne's models. On the other hand, under B conditions the divided field presentation results in right GP speeding of RTs from both VFs.

This enhanced performance is congruent with the fact that about half of the CLEM studies report a predominant association of rightward CLEMs and VQs. The GP effect is also consistent with the reports of right GP speeding of RTs when using the lexical decision task (Tressoldi, 1987). Further meaningful comparisons with the reverse CLEM literature is virtually impossible due to the wide variety of tasks used therein, their dissimilarity to the ones used in this research programme, and their methodological shortcomings.

The only reliable effects of GP that were found with vertical eye movements required that all of the data from the first three experiments be combined. Even then the observed GP x VF interaction was small in both magnitude and effect size. This may be due to the fact that locus of control for vertical movements is in the midbrain (Bender, 1980) and thus too far removed from the cortical areas involved with task performance to produce much direct neural interaction. More importantly, the interaction appeared to be due to two opposed GP effects. RTs in the LVF were slowest in GP3, which is in accordance with prediction made from Kinsbourne's models. At the same time, RTs in the RVF were fastest in GP3 which is contrary to the prediction. This peculiar interaction will be considered more fully later.

Across the horizontal GPs, the interaction that appeared with VQAs in the R condition is directly counter to the predicted

interaction based on hemispheric arousal. If, however, one assumes that eye movements convert the experimental requirements into a dual task situation then intrahemispheric interference (Green, 1984; Kinsbourne & Hicks, 1978) can be used to account for the observed interaction. In such a situation, a contralateral eye movement should be associated with decreased performance, but with little or no effect when an ipsilateral eye movement is made. However, in the B condition this explanation can be used only for the LVF. Intrahemispheric arousal must be used to account for the RVF RT/GP profile of the combined experiments (Figure 6). Such selective use of arousal and interference is plainly out of order and this misuse is even more evident when the results from the SQA (rectangles) are considered. Here, unlike the VQAs, there were no differences between the two conditions. It may seem that a modality change, VQA to SQA, might alter the way that interference and arousal combine with eye movements by virtue of the different functional asymmetry associated with the two modes. But with a divided field presentation, these effects ought to be independent of modality, because, under the experimental conditions, the hemisphere receiving the stimulus is believed to do most of the processing (Ragot & Lesevre, 1986; Sergent, 1983).

The implications of the GP effect found under B conditions can be considered from a slightly different point of view. The key prediction made from Kinsbourne's models is that when

a mental set favouring one hemisphere is established (however produced) then a contralateral performance advantage will be obtained. The results from the B conditions, using VQAs as stimuli, revealed three features that contradict this prediction. When a right GP was used to produce a set favouring the left hemisphere, the RTs for *both* VFs were enhanced equally compared to the, presumably, unbiased central GP. Conversely, when a left GP was used to produce a set favouring the right hemisphere, no effect on RT was found for either VF. One must therefore conclude that the GP effect that was found is independent of any induced mental set or arousal of a particular hemisphere. Furthermore, since the RVF advantage was constant across the horizontal GPs, it also must be independent of the set or arousal induced by GP.

Neither arousal nor interference, as the terms are used by Kinsbourne, can account for the results of the present experiments. Consideration of the anatomical loci involved in task performance and eye movements may go someway to explaining why.

Saccades are initiated in the frontal eye fields of the frontal lobes. The latter are know to be involved in memory and other high level cognitive processes. However, EEG studies have shown that the asymmetric activation due to verbal cognition is found primarily over the parietal lobes rather than the frontal ones (Davidson, 1988). Also,

Davidson et al. (1990) failed to find any correlation between frontal EEG records and task related asymmetries after eye movement artefacts had been removed. This may mean that the neural connectivity between the locus of cognitive activity in the parietal lobes and the locus of saccade initiation in the frontal lobes is not as close as Kinsbourne seems to assume. This EEG evidence appears to contradict the inference by Kinsbourne and Hicks (1978) that:

> "The functional distance between the left sided
> verbal processor and the left lateralized
> rightward orienting centre makes the rightward
> attention during verbal processing compatible
> with functional brain organization and
> therefore efficiently achievable" (p.356).

This is an important point because Kinsbourne and Hicks' description of "functional distance" appears to confuse neuroanatomical connectivity with spatial proximity. This is well illustrated by their description of functional distance:

> Any spread of activation to the opposing centre
> on the other side of the brain is naturally
> more limited because of the functionally
> greater distance [sic] to be traversed and
> therefore insufficient to off-set this
> asymmetric effect." (p. 355)

It is very difficult from this to distinguish between functional distance as a neural connectivity concept and the alternative physical proximity concept. Hence, given the EEG evidence, interaction between cognition and eye movements may not actually happen as presumed by Kinsbourne's (1972) model,

and some other explanation for the observed interaction must be found.

The GP effect found for VQAs under B conditions is a puzzle and cannot be readily accounted for. The difference between the R and B conditions when VQAs are used suggests that oculomotor control of continual and frequent movements differs from that for steady gaze direction. Neuro-anatomical evidence shows that this is in fact the case (Bender, 1980). Onset and termination of horizontal saccades is initiated in the frontal eye fields of the frontal lobes and thence by direct connections to the oculomotor control system in the midbrain. The saccades are directed contralaterally to the initiating cerebral hemisphere. Gaze holding, which is primarily maintained by the midbrain, also involves the maintenance of attention. This in turn is maintained by the parietal eye fields which are only indirectly connected to the midbrain (Leichnitz & Goldberg, 1988). Therefore, it is possible that oculomotor control is involved to some extent in the different effects noted for R and B conditions.

The difference between the R and B conditions with VQAs was due to the RVF alone, since under R conditions the LVF performance was similar to both the LVF and RVF performances under B conditions. Although the similarity of the LVF performances under R and B conditions may conceivably have a different origin, intuitively this seems rather implausible.

Therefore, there must be some important difference between the two hemispheres in saccade initiation that is revealed by the RVF alone. It may be that the link between verbal processing and saccade initiation differs in the two hemispheres. In particular, there is evidence that the motor control of voice production is a strictly left hemisphere function (Moscovitch, 1973). It is also possible that subvocalization as a strategy may have occurred during each trial (Davidson et al., 1990). Consequently, motor interference may also have occurred between eye movements and any subvocalization stage of the task performance. Such relatively close coupling between subvocalization and saccades is made plausible by considering the reading process. Intuitively, subvocalization during reading is highly likely, and as reading skills develop, the coupling between subvocalization and directed eye movements would intensify considerably.

The idea of interference between subvocalization and saccades may also be able to account for the peculiar GP x VF interaction that was found over the vertical GPs when using VQAs. It was earlier noted that horizontal saccades and gaze holding originate in the frontal and parietal lobes respectively. However, both vertical saccades *and* vertical gaze holding have a common origin in the midbrain (Bender 1980). Hence, if there is neural connectivity between the midbrain and the voice production centre in the left hemisphere, motor-motor interference from subvocalization

could occur with both saccades and steady gaze. This would
lead to slower RTs in the RVF when the eyes move vertically
away from the central GP3. Such interference would not occur
in the right hemisphere. There, arousal may possibly occur,
being due to saccades or gaze holding, Such arousal would act
unopposed, giving rise to faster RTs when the eyes move
vertically away from the central GP3.

Even though the vertical GP x VF interaction supports the idea
of interference between subvocalization and saccade control,
the support is not strong. The relative variation between the
central GPs and the upper and lower ones was less than four
msec, or less than eight msec in all. Furthermore, the effect
size was small, needing over 40 subjects before it became
evident.

Motor interference can account for the RVF performance under
R conditions over the horizontal GPs. In conjunction with
arousal it might also account for the GP x VF interaction
that was found over the vertical GPs under both R and B
conditions. But, it does not account for either the
rightward bias shown by the LVF under R conditions over the
horizontal GPs, or for the same rightward bias shown by both
VFs under B conditions. Unlike horizontal saccades which
require the oculomotor system to be closely coupled with the
frontal eye fields, a steady gaze is maintained by loose
connections with the parietal eye fields. Even though the

parietal lobes are likely to be engaged by the experimental task (Davidson, 1988), arousal or interference is less likely to occur because the neural connections with the oculomotor centres are diffused (Lechnitz & Goldberg, 1988). So the interaction that was found under R conditions when using VQAs would not be expected under B conditions. But at the same time there is no apparent reason to expect a steady gaze to affect task performance at all. Hence, from anatomical considerations one would therefore not expect GP effects to be observed.

Another possibility is that humans have a perceptual bias towards one or the other hemispace (Bradshaw, Burden, & Nettleton, 1986; Bradshaw & Nettleton, 1983; Bradshaw & Pierson, 1985). For instance, being right handed may lead to a rightward perceptual bias and there is some evidence for this actually occurring (Bryden, 1978; Hellige, 1993). Since all subjects used in the present programme were right handed they would therefore be expected to show a rightward perceptual bias. This possibility is supported by Rosenberg et al. (1983) who concluded that the direction of vertical CLEMs was habitual and was related to the height of their subjects. They also reported that the occurrence of horizontal CLEMs was related to the wearing of spectacles. However, explaining a rightward bias by appealing to habitual processes is contra-indicated by the lack of any effect of GP when using rectangles as SQAs. Using the logic of the earlier argument, the absence of an interaction under R

conditions might indicate that there was no subvocalization component to the task. In which case there should have been a GP main effect under B conditions and an LVF bias under R conditions towards the right hemispace. The absence of such a bias appears to be contrary to this "habitual" explanation. At the same time, however, the absence of bias when SQAs were used may be due to other processes.

It will be recalled that in ordinary CLEM studies, stares frequently accompanied the processing of SQs. These stares were traced to the fact that during the processing of SQs, ocular motility was reduced below a resting baseline level. VQs, on the other hand, resulted in an increase in motility above base line levels (Ehrlichman & Barrett, 1983a; Hiscock & Bergstrom, 1981; Weiner & Ehrlichman, 1976). In short, saccades are suppressed during visualization. It is therefore plausible that when SQAs are processed, this same suppression of saccades is automatically invoked thereby preventing a rightward bias from appearing. This possibility is supported by Rosenberg (1980) who found that when processing SQs, OKN movements were suppressed relative to when processing VQs. The hypothesis could be tested by repeating Rosenberg's OKN experiment and manipulating the degree of verbal content in the SQAs while GP is also varied. It can also be noted that both increased ocular motility and increased OKN when processing VQs is consistent with the earlier suggestion that motor control of subvocalization and saccades become closely coupled due to reading development.

Because of this presumed close coupling, subvocalization may actively initiate undirected saccades.

Intrahemispheric interference between subvocalization and saccades within the left hemisphere is also consistent with the results from a number of dual task experiments. For instance, Hellige (Hellige & Cox, 1976; Hellige, Cox & Litvac, 1979) found that a concurrent verbal memory task had no effect on recognition accuracy when stimuli were presented to the LVF. However, RVF performance was improved with low concurrent memory loads, but impaired with high loads. Hellige (Hellige, 1993) has interpreted these and other similar results in terms of hemispheric specific arousal and interference due to cognitive processing. Alternatively, Hellige's results can also be explained by replacing the unspecified cognitive processes with the more specific motor activity accompanying subvocalization.

It seems that the simplest explanation for the GP effects that have been described here runs as follows. Arousal, especially as used by Kinsbourne (1972), cannot account for the GP x VF interaction obtained in the present studies. General intrahemispheric interference fares only a little better by accounting for the interaction under R conditions but only if the interaction has a different origin to the GP effect under B conditions. Furthermore, neuroanatomical considerations make unspecified intrahemispheric interfer- ence rather implausible. However, motor interference within

the left hemisphere between saccade control and subvocalization is a possible reason for the apparent lability of the RVF between R and B conditions. The frequent saccades occurring during R conditions interact with the ongoing subvocalization sufficiently to overcome an habitual bias by the right hemisphere towards the right hemispace. Assuming that no subvocalization occurs within the right hemisphere, the rightward bias in the LVF RTs is unaffected. However, under B conditions, when a steady gaze is maintained, the absence of saccades means that interaction between saccades and subvocalization does not occur and a normal right hemispace bias is shown by both left and right hemisphere. The absence of any bias when processing SQAs is due to the automatic invocation of the mechanism that actively suppresses saccades when engaged in internal visualizing. When vertical movements take place, left hemisphere interference between oculomotor control and subvocalization impairs RVF performance when the eyes move away from the central position; at the same time, right hemisphere arousal due to oculomotor control facilitates LVF performance.

Two further points, difficulty and modality, deserve comment. The initial impulse to investigate the interaction between GP and task difficulty came from Ehrlichman and Weinberger's (1978) comment that over-learned material requiring simple responses seldom produced CLEMs. The tasks used in the present research were simple, well practised requiring a simple response; nevertheless, GP was shown to affect RT. One

reason for this apparent discrepancy is that it may simply reflect the difference between orthodox CLEM and reverse CLEM methodology. On the other hand, it may indicate that the method used in this research programme is more sensitive and better able to detect GP effects than using spoken stimuli and spoken responses (e.g., Walker et al., 1982).

The second point to be considered is task modality. That is, do GP effects differ when VQAs or SQAs are used as stimuli? The results of Experiment 4 suggest that they do. There, other than the VF main effect, there was very little difference between either the LVF and RVF, or between conditions; the one minor difference could be traced to an aberrant individual median RT. Failing to find any difference between the LVF and RVF for either GP or Condition suggests that when SQAs are used, processing is similar within the two hemispheres. This is consistent with the psycho-physiological evidence, reviewed in the Introduction, that shows that visual-spatial tasks give symmetrical activation of the two hemispheres.

The results of this program can now be examined within the larger context of Kinsbourne's (1970) attentional gradient model and then within the functional laterality framework.

Wider issues

Attentional gradient

In addition to directly testing the dominant theoretical account of CLEMs, the methodology also allowed the underlying attentional gradient model of cerebral asymmetry to be tested (Kinsbourne, 1970). This was done by overtly and systematically directing attention to one hemispace or the other, a method that has not previously been reported. The results of these experiments extend further the list of failures to support Kinsbourne's model (Bradshaw & Nettleton, 1983). This lack of support for the model, even in its most developed functional distance form, can in part be traced to internal inconsistencies within it.

Consider the effect of a CLEM made ipsilateral to the engaged hemisphere. Kinsbourne makes no mention of these but since ipsilateral movements would be driven by the contralateral unengaged hemisphere they should have no effect. Hence, performance should be inferior with ipsilateral CLEMs compared to when contralateral ones are made. But, functional distance is also used (Kinsbourne & Hicks, 1978)) to account for dual task interference, the logic of which must also apply to CLEMs. Thus, an eye movement activating the contralateral frontal eye field is a task imposed upon the contralateral hemisphere. If that hemisphere is required concurrently to carry out some other task, the extra processing load imposed by the eye movement will, due to the

close functional distance, interfere with the task performance. That is, a contralateral CLEM will impair performance. Conversely, an ipsilateral movement would not activate the engaged hemisphere and no interference would occur, resulting in a superior performance compared to when contralateral movements were made. The model is therefore internally inconsistent in these respects. One can, of course, specify that an eye movement provides too little load to interfere with performance but enough to prime the active hemisphere, as Kinsbourne has done (Ledlow, Swanson, & Kinsbourne, 1978).

Although Kinsbourne's theorizing has generated a fair amount of research, support for his theory has been at best equivocal and often contrary. Bradshaw and Nettleton (1983), after reviewing and evaluating the relevant literature, concluded that while attentional gradients probably contributed to cerebral functional laterality, the notion would have to be combined with many other approaches to produce a satisfactory accounting. But this may be a rather optimistic conclusion. The weaknesses in Kinsbourne's theorizing and the lack of solid empirical support suggest that a radically altered approach may be required.

Functional laterality

The attractive simplicity of the notions of attentional gradient and functional distance allowed Kinsbourne's (1970) theory to fit comfortably into the more general ideas of

functional cerebral laterality. However, the ready
acceptance of these ideas can be attributed to the almost
universal acceptance of the notion of dichotomized functional
cerebral laterality. It is the unsoundness of the ideas
contained in "functional cerebral laterality" that renders
futile any attempts to rescue Kinsbourne's theory.

In its simplest form the notion of functional laterality
presumes that each cerebral hemisphere is specialized to
carry out different but complementary psychological
functions. For instance, the left hemisphere is specialized
for verbal and logical or numerical functions. The right
hemisphere carries out musical, visual and emotive functions.
Over the years these various functions have been elaborated
into various polarities or dichotomies (see Bradshaw &
Nettleton, 1983).

The original polarization into verbal and visual-spatial
functions was based on data obtained mainly from split brain
subjects. The relevance of models of split brain performance
to the behaviour of the normal intact brain is arguable
(e.g., Moscovitch, 1973; Zaidel, 1983). As Bertelson (1982)
points out, while the original dichotomy was the descriptive
term that seemed to best describe the data, such dichotomies
are *post hoc* explanations which are now used as causative
explanations to account for the performances of normal
subjects. In particular, in laterality studies where
contralateral sensory-motor innervation has been used to

present stimuli to one or the other cerebral hemispheres, obtained lateral advantages are explained in terms of the putative functions based on those advantages. The suspect logic involved in this reasoning has been noted on a number of occasions.

For example, Hardyck (1983) emphasises that allowing descriptive terminology to be its own referent is semicircular logic leading to ambiguity in understanding. Sergent (1982, 1983), having twice challenged the illogic, is delightfully abrasive, writing:

> "This is a bizarre situation in which what one is supposed to explain (hemispheric competence) through the use of a particular task (e.g. facial recognition) serves to explain the performance on this task on the ground of unexplained hemispheric superiority." (1982, p. 267, note 8).

This unsatisfactory situation is only marginally assisted by the results of those studies where asymmetric activation of the cerebral hemispheres was measured independently. The psychophysiological studies reviewed earlier demonstrate only that verbal tasks produce asymmetric levels of activity in the hemispheres when both are activated, regardless of the nature of the task. Concluding that language processing, as distinct from voice production, is the sole province of the left hemisphere cannot be justified when both hemispheres are simultaneously activated. Even the more restricted statement that the left hemisphere is more involved in language

processing than the right must be treated cautiously.
Sergent (1982) has even suggested that when task requirements
are equalised in terms of the sensori-motor resolution of the
two hemispheres there are no cognitive differences between
them. Searlman (1977) concluded that the case for unilateral
specialization for language was made more often for
production than for comprehension (supported, in part, by
Zaidel, 1983). Hammond (1982) has noted that if the two
hemispheres are specialized, then they are physiologically,
not psychologically, specialized. Certainly, psychological
functions cannot be assigned to various parts of the brain
(Bullock, 1965; Luria, 1966, both cited in Sergent, 1983).
One can go further and suggest that the only strictly
lateralized language function for which there is any direct
evidence is the motor control of speech. Since bilateral
control of speech production would probably result in
competition between the hemispheres giving rise to such
problems as stuttering (Moscovitch, 1973), unilateral speech
control would be a natural evolutionary outcome. Any of the
several models chosen from strict localisation, unilateral
inhibition or output allocation (Allen, 1983) would be
plausible options to describe the mechanism of unilateral
motor control of speech. With unilateral speech control any
task that permitted subvocalization to occur might be
expected to produce lateral advantages that may be spuriously
attributed to hemispherical specialization. Davidson et al.
(1990) has discussed this problem as it relates to artifacts
in EEG studies of laterality effects.

One can only conclude that the beliefs regarding the nature of cerebral laterality are premature, receiving only partial empirical support. This means that models of laterality that go beyond physiological mechanisms and incorporate notions of the psychological nature of laterality are suspect. (This does not mean that all questions can be answered by physiological models.) Even if such models are ignored, there are at least a dozen apparently viable models remaining in Allen's (1983) classification from which to chose. Unfortunately, any model that specifies differing performances by the two hemispheres must specify the nature of those differences, at least by implication. This immediately reintroduces the circularity that has just been considered, rendering suspect most of the remaining models. In short, two distinct topics, the nature of cerebral cognitive lateralisation and the mechanics of that lateralisation have been confounded, and perhaps even further confounded with sensory-motor lateralisation.

Confounding the nature of cerebral laterality with possible mechanisms led to such a confused situation that Friedman and Polson (1981) complained about:

> "(a) the apparent capriciousness of the phenomena, (b) the defying of replication, (c) the wide range of individual differences even among supposed homogenous populations, (d) the lack of individual consistency and the consequent lack of a global theory that could account for even the few observed consistencies." (p. 1031).

Cohen (1982) provided an excellent summary of the situation, writing:

> "In consequence, we are in the position of explaining results (which we often cannot predict) in terms of mechanisms (which we do not fully understand) and factors (which we have failed to define) and hypothesised operations (for which there is no independent validation)." (p. 110).

A reasonable conclusion to draw from the foregoing discussion of cerebral laterality is that the only valid models of cerebral cognitive functioning are those that make no reference to a dichotomized lateralisation of that functioning (speech control being the possible exception). There are only two ways to satisfy this requirement; either the two hemispheres simply duplicate one another, or, processing is distributed between both hemispheres in a complex individual-by-task-by-situation pattern. In either case, the notion of dichotomously lateralized cognitive functions may have little real meaning. This view is supported by Beaumont, Young, and McManus (1984) who take the position that cerebral hemisphere dichotomies are "at least unsubstantiated and most likely wrong in principle." (p. 206).

A most remarkable feature of the preoccupation with lateralized dichotomies is the persistence of the notion despite the strong countervailing evidence that has been available for quite some time. For instance, Bryden (1965) found that perceptual asymmetry scores on a dichotic listening test of number recognition were uncorrelated with

scores on a divided field test of letter recognition. This
lack of correlation was also found when the two tasks were
designed to be analogous (Zurif & Bryden, 1969). Extensive
reviews of the countervailing evidence are to be found in
Colbourn (1978), Hellige (1983) and Richardson (1976).

Persevering with the idea of dichotomous lateralization may
be due in part to a failure to give equal attention to both
theoretical basics and the instruments used to test and
establish theory. This idea has been noted by Colbourn
(1978) and extensively developed by Samar (1983) who gave a
particularly damning commentary of the manner in which
cerebral laterality has been confused with performance
laterality. This issue itself has been developed in greater
detail by Davidson (1988). The primary instrument for
cerebral laterality studies with normal (i.e., non clinical)
subjects has been to present stimuli using visual half
fields, dichotic listening or dihaptic touch methods. It has
been generally assumed that measured perceptual asymmetries
are a more or less direct reflection of the underlying
cerebral asymmetry (e.g., White, 1973). As a consequence it
is common practice to use, for instance, LVF and Right
Hemisphere as interchangeable terms (e.g., Hellige, 1993, p.
17) which confuses the distinction between the observed and
inferred entities in laterality experiments. Also, the
magnitude of the observed perceptual entities has often been
taken as a measure of the strength of functional
lateralization. This has led to the development of a number

of "laterality indices", the utility of which is decidedly dubious since, as Colbourn (1978) observed, no particular relationship has been demonstrated between perceptual asymmetry and the presumed underlying cerebral asymmetry (see also Hellige, 1983; Richardson, 1976). Happily, this unsatisfactory state of affairs has begun to change.

Modern trends

The emphasis of recent theoretical and experimental reports has shifted away from functional laterality *per se*. Attention is now being focused on the complex interactions among the factors that intervene between stimulus presentation and response output thereby producing an overall asymmetry in task performance. It is now possible to discern a number of experimental themes that address the validity of the functional laterality issue: (i) orthogonally varying two or more independent variables; (ii) forcing the same stimuli to be processed in two or more different ways; (iii) ensuring that the task really is processed by only one hemisphere and without assuming any functional specialisation; (iv) taking two or more independent measures simultaneously; (v) examining how the hemispheres cooperate rather than searching for differences between them. Naturally, these themes are often combined in any one experiment and while it is not always made explicit, they are, in effect, examining the validity of the test instrument; namely, lateralized stimulus presentation and its relationship to the underlying cerebral asymmetries. A few examples will suffice to illustrate the

trend of methodological shifts and how the results bear on the laterality issue.

Samar (1983) reported an extensive study that used a multi-dimensional EEG/divided field technique and, in part, explicitly examined the lateral presentation methodology. Two classes of stimuli were used, word/non-words and parallelism of rotated line orientations, thereby tapping linguistic and spatial processes. The relevant dependent variables were concurrent performance RT and accuracy measures, and temporal/parietal EEG potentials at 80 time points during each trial. The EEG potentials were entered into a time point factor analytic program which produced 13 factors. Since the factors were, by definition, statistically independent, they were used as the dependent variables in the subsequent ANOVAs. Several important results were reported. There were at least three independent processes, identified by the first three factors, associated with task dependent asymmetric hemispheric patterns. The second factor appeared to be associated with the left hemisphere lexical decision where it discriminated between the words and non-words. Further analyses used individual lateral difference scores for the RT and accuracy data together with factor difference scores. Multiple regression analyses using the factor difference scores were made with RT and accuracy asymmetry being the target variables. RT data were unpredictable, but accuracy data could be reliably predicted both for types of task and for sex. No more than

four factors were required for any regression equation and
only a handful of factors were used. Correlation
coefficients were impressively high, three being above 0.90
and the lowest being 0.82. Samar's results demonstrate that
VF asymmetries are related to the asymmetry distributions of
several underlying processing events (represented by EEG
factor scores). There is no doubt on this evidence that VF
performance asymmetries are the resultant of several distinct
task-related events distributed asymmetrically over the
hemispheres. This is in sharp contrast to the idea of a
dichotomous functional lateralization but can be readily
accommodated by the parallel independent resource pool model
developed by Friedman and Polson (1981).

Friedman and Polson's (1981) model treats the two cerebral
hemispheres as being independent processing resource pools
that can cooperate in overall task performance. To test the
model they vary the common dual task method by manipulating
the payoffs for each task and comparing the resulting dual
task performances with those for the single tasks done
separately (e.g., Freidman, Polson, & Dafoe, 1988). The
patterns of interference that are observed are consistent
with resource sharing between the two hemispheres but may be
modified by the subject's expectancies. The evidence for the
independence of hemispheric resources has been further
extended to other dual task combinations (Lamberts &
d'Ydewalle, 1990) where it was also shown that the resource
composition of task expectancies depended upon the nature of

the expected task. This is suggestive of a form of meta control (Levy & Trevarthen, 1985).

Avant, Thieman, and Miller (1993), who also argued for meta control, investigated the prerecognition visual processing of letter pairs using divided VF presentation. Letters were combinations of upright, inverted or mirror imaged versions. A trial consisted of two pre- and post-masked 10 msec presentations of a letter pair with subjects judging which presentation had the longest duration. Recognition of the letters themselves were at chance levels but highly significant interactions between VF and the stimulus pairs were found. VF advantages depended upon whether the letter pairs were normal, inverted or mirror imaged and no interactions were found when bilateral presentation was used. The results demonstrated that each hemisphere was capable of performing its own prerecognition processing, which accords with the idea that they are a pair of independent resource pools. Also, VF advantages were clearly shown at a very early processing stage, even earlier than the feature detection level that obtained in Polich (1993). Furthermore, both the direction and magnitude of the VF advantages depended upon the precise configuration of the stimuli. This latter aspect of the results was interpreted in terms of a form of central meta control that caused the outer perceptual processes to give weight to the significance of the stimuli as well as to their features. More importantly, the results show that VF asymmetries depend more upon the precise

properties of the stimuli rather than any inherent functional asymmetry of the hemispheres.

This view has received support from a number of sources including Christman (1987, 1990). He used a divided VF paradigm and a temporal integration task to test the spatial frequency model of cerebral asymmetries (Sergent, 1982). The separate components of a visual pattern were exposed briefly in two successive 8 msec intervals. When integrated over time the patterns in the two intervals were seen as a single digit which the subject reported. Stimulus size, retinal eccentricity, luminance and dioptic blurring were varied both separately and orthogonally and all were shown to interact with VF advantage. The conclusion drawn was that hemispheric laterality was not a "monolithic entity" but that perceptual asymmetries are determined by the perceptual parameters of the input. These include an interaction between the spatial frequencies available and the frequencies required by the processing demands.

Very few assumptions about cerebral lateralisation were made in these more recent reports, the main ones being that stimuli presented to one VF goes solely to the contralateral hemisphere and that the experimental conditions were sufficient to restrict most of the processing to the hemisphere that received the information. The strongest assumptions, made by Friedman et al. (1988), were that language production, including subvocalization, was

restricted to the left hemisphere and that the control of motor output was contralaterally organised. A very satisfying feature of the trends shown by these studies is the clear rejection of any ideas of a dichotomous division of psychological functions between the cerebral hemispheres. Instead, a very complex picture of cerebral functioning has begun to emerge.

Perceptual asymmetry effects appear at a very early level, so early that one wonders if they might even be found at the retina itself. These asymmetries are determined by interactions among the stimulus' physical parameters and with the psychological context of the situation. The interaction with the psychological context (e.g., meaning, expectancies, salience) means that the perceptual asymmetries are mediated by more central processes in a directed way. In other words, the direction of the asymmetry is subject to meta control. Depending upon the combination of stimulus properties and task requirements, multiple individual processing events occur; these events may be confined to one cerebral hemisphere which can operate independently of the other. Or, the two hemispheres may cooperate in an unknown and complex manner. Consequently, the final perceptual asymmetry is the resultant of a complex interplay of individual asymmetric processes.

It is within this conceptual framework that the series of experiments described in this dissertation should be evaluated.

Programme evaluation

The reverse CLEM methodology developed here was a deliberate attempt to avoid the ambiguities and circular logic implicit in the normal CLEM methods. By making both GP and VF into independent variables the stimulus information was restricted, initially, to the targeted hemisphere. The only assumptions were those of the contralateral innervation of the retinal half fields and the restriction of processing to the targeted hemisphere. There is ample evidence that, given the experimental conditions used here, these two assumptions do hold (Ragot & Lesevre, 1986; Sergent, 1983). Furthermore, the reverse CLEM method avoided entirely the question of verbal or visual-spatial specializations and therefore the circularities of functional lateralization. The methodology also allowed the two main independent variables to be varied both simultaneously and orthogonally within the one experiment, and two other variables, Condition and Task Modality, could be varied while keeping the same main conditions over several experiments. It can be seen that, methodologically, the experiments described here fall squarely within the framework of the recent developments in laterality research.

The results and conclusions are also firmly in the spirit of those same recent developments. The GP x VF interaction that was found under R conditions could not be interpreted as being due to intrahemispheric arousal or interference in the sense that Kinsbourne has used these terms. It was reasonably symmetrical over both hemispheres suggesting that the two hemispheres were acting independently. Left hemisphere interference between the motor control of saccades and that of subvocalization is a plausible alternative account for the interaction. The GP effect that occurred when the trials were blocked onto one GP suggests some form of linkage between the two hemispheres. Whether this link was a result of dominance by one or the other hemisphere or due to a biased common input or output stage is not known. Alternatively, the two hemispheres may have a bias towards the same hemispace and, thus, were acting independently of one another. Whatever the causes of the GP effect and GP x VF interaction, the earlier discussion was in terms of physiological functioning, not psychological functioning and thus is related to the notion of distributed processes. Certainly the approach adopted here provides a more coherent account than Kinsbourne's attentional gradient model which is based on the dichotomized function notion.

Problems, Difficulties and Mistakes

Methodological issues

In any experiment there are always a whole host of variables that can influence the outcome. This is especially the case in psychological experiments where individual differences can easily render the results uninterpretable. Accordingly, every effort must be made to minimize the effect of variables that are unrelated to the issues under investigation. Because the extraneous variables cannot always be identified attempts are made to control only those that can be recognised as potentially relevant to the experiment. Often the control requires some form of compromise between the desirable and the attainable and this compromise may introduce unwanted difficulties in interpreting the results of the experiment.

The study by Andreasen (1988) produced such a complication. He used two-fingered unimanual responding to obtain RT measures in a divided visual field experiment. In an effort to maintain constant conditions across the subjects, all subjects responded with their right hands. The absence of response hand counterbalancing produced a noticeable S-R compatibility effect (Fitts & Seager, 1953) which made the interpretation of the results more difficult than might otherwise have been. Although the effect did not reach significance, it was large enough to be of concern as a source of unwanted error variance. There are other potential

sources of error variance. All of sex, handedness, intrahemispheric interference, hand by task interactions, fast left responding and fast or slow finger appear to be implicated to some degree. These factors are therefore examined below with the aim of assessing their likely impact on the outcome of the present experimental programme.

S-R compatibility

S-R compatibility is a phenomenon where the relative congruence between stimulus and response properties leads to RT differences that reflect those congruencies. For instance, suppose that subjects are to respond to one of two horizontally arranged stimulus lights by pressing one of two response buttons that have a left-right (L-R) layout. RTs will be faster for L-L and R-R light button pairs than for L-R or R-L pairs.

S-R compatibility usually refers to either direct or indirect spatial compatibility (Heister & Shroeder-Heister, 1987). S-R compatibility is a very robust phenomenon. Not only does it occur when the congruencies are deliberately established, but also when the congruencies are irrelevant for response selection. This latter occurrence, sometimes known as the Simon effect (Hedge & Marsh, 1975), is sufficiently robust to be evident when S-R compatible distracter cues are used (Simon & Craft, 1970). It also occurs when the hands are crossed in front of the body (Berluchi, Crea, Di Stefano, & Tassinarri, 1977), located to one side only in bimanual

responding (Nicoletti, Anzola, Luppino, Rizzolatti, & Umilta, 1982) or when a near/far or top/bottom response dichotomy is used (Nicoletti & Umilta, 1984). It even withstands reorienting the body with respect to gravity (Ladavas & Moscovitch, 1984). The effect is additive with other sensory-motor factors (Hasbroucq, Guiard, & Kornblum, 1989) and occurs with a wide range of visual (e.g., Katz, 1981), auditory (e.g., Simon & Craft, 1970) and tactile stimuli (e.g., Hasbroucq et al., 1989). The effect also occurs with symbolic relationships, such as "Left-Right" (Whitaker, 1982), or directional arrows (Arend & Wandmacher, 1987) and can also arise in tasks that do *not* involve a choice between concurrent response locations (Guiard, 1984).

Most importantly, it is so ubiquitous in divided field, two-choice RT studies that Heister and Shroeder-Heister (1985, 1987) have suggested that many results attributed to cerebral laterality may well be due to unsuspected S-R compatibility effects. With respect to divided field studies, a most important study that has not, as yet, been replicated, was carried out by Ragot and Lesevre (1986). They conducted a divided field, two-choice RT experiment and obtained concurrent electro-physiological and RT measures from the separate hemispheres. The results showed that *intrahemispheric* S-R compatibility effects occur, that they are separate for each cerebral hemisphere, that the effects do not differ for the two hemispheres and that fovea presentation magnifies the effects.

Attempts to account for S-R compatibility include:
attentional coding and spatial coding (Umilta & Nicoletti,
1985), dimensional overlap (Kornblum, Hasbroucq, & Osman,
1990), and a memory scan/response selection rule model
(Hasbroucq, Guiard, & Ottomani, 1990). Ragot & Lesevre
(1986) argue that neither the attentional nor the coding
accounting is adequate because they found that S-R
compatibility effects were independently evident in both
hemispheres at equal strength. Also, other studies have
shown that the effects are indifferent to changes in limb or
body orientation. The other two models have yet to be
critically evaluated.

Regardless of how S-R compatibility effects are generated
within the nervous system, they are clearly so robust,
pervasive and ubiquitous that any divided field study using
normal subjects will be contaminated by them.

The insidious nature of S-R compatibility meant that attempts
to prevent it occurring would be a futile endeavour. The
only realistic option in the present programme was to use
within-subjects counterbalancing and accept that additional
sessions would be needed to avoid confusing the subjects with
response finger changes. The alternative **between**-subjects
counterbalancing would have been too inefficient in terms of
subject numbers, and, as discussed later, would have
introduced additional statistical problems into the data
analysis.

Sex

Fairweather (1982), reviewed 129 divided field experiments and found only 26 that produced significant differences that could be attributed to gender. Within the verbal domain very few differences were found. More differences were found in the nonverbal domain but no consistency within methodology or laterality could be discerned. He concluded that the evidence did not justify the inclusion of sex in any theory of functional cerebral laterality, nor should cerebral laterality be included in any theory of sex differences. Later studies by Bradshaw and Pierson (1985), Ladavas and Moscovitch (1984), Liederman, Merola, and Martinez (1985), Peters (1983), Sergent (1982), and Whitaker (1982) give further support to these conclusions. However, Heister (1984) found a sex difference in motor responding to unfamiliar words and that this difference could be traced to the male right hemisphere. Heister and Shroeder-Heister (1987) also found that for difficult cognitive tasks, sex had a strong influence on S-R compatibility effects.

Despite the odd study suggesting gender influences, a reasonable conclusion was that sex could be disregarded for gaze position (GP) experiments.

Hand X Task interactions

Heister (1984) observed a tendency for the left hand (LH) to be faster than the right hand (RH) for lexical tasks. She also noted that similar effects had been reported elsewhere

(Day, 1979; Straus & Moscovitch, 1979, both cited in Heister, 1984; Shannon, 1979). However, an examination of an additional 22 divided field studies (taken from the references for this dissertation), giving a total of 26 containing 49 experiments, gave the following analysis. For alphanumeric stimuli, 10 out of 10 null results. For non-alphanumerics, three significant left hand, five significant right hand and 31 null results.

With null results outnumbering the combined totals of significant results for both classes of stimuli, the risk of finding hand x task interactions in GP experiments was also disregarded.

Fast hand effects

The analysis of the results of studies where a Hand x Task interaction may have been found also failed to reveal any consistent main effect for response hand. All 10 alphanumeric experiments discovered gave null results for hand, while 27 of 39 non-alphanumeric experiments also gave null results. In other words, neither hand has any consistent speed advantage over the other. However, Annett and Annett (1979) found that 25% of their RH subjects were consistently faster with the RH than the LH while this was reversed for the remaining 75%. Obviously, while individual variation needs to be considered, appropriate counter-balancing should nullify this problem.

Handedness

Annett (1982) reviewed 28 experiments reported in 24 studies for the effects of handedness. She concluded that there was no good evidence to show that left handers demonstrated any form of cerebral laterality in divided field experiments. However, left handers often gave similar results to right handers but with a reduced magnitude of effect. Additionally, right handers showed a consistent RVF superiority for alphanumeric stimuli and a less consistent LVF superiority for non-alphanumerics. Therefore, to maximize the size of any experimental effects left handers were excluded from the potential subject pool for the present programme.

Slow finger syndrome

Reeve and Proctor (1988), over a series of four experiments, found a consistent difference in RTs for different fingers. Index fingers were significantly slower than middle fingers in an RT task. This effect was also noted by Rosenbaum and Kornblum (1982). Annett and Annett (1979) found that the effect was restricted to the *right* index finger and cite Welford (1971) as finding the same effect. They suggest that because the index finger is used for fine manipulations, more information is processed leading to slower RTs. To circumvent this particular effect the middle fingers only were used for responding in the present research.

Intrahemispheric interference

Several studies have shown that responding with two fingers
of one hand in a two choice RT task is systematically slower
than using one finger on each hand (Annett & Annett, 1979;
Hick, 1952, cited in Annett & Annett, 1979; Kornblum, 1965;
Reeve & Proctor, 1988; Rosenbaum & Kornblum, 1982). All
authors attribute this to intrahemispheric competition of
response alternatives leading to within-hand slowing.
However, this effect can be eliminated by using long (3 sec)
precuing intervals. Green (1984) has investigated
intrahemispheric interference and found that it could be
reduced or eliminated by simplifying either the task or the
response. For instance, interference occurring in a two
choice RT experiment could be removed by adopting a go-nogo
format; that is, subjects responded to only one of the two
alternatives.

Closely related to the advantage of different hand over same
hand responding is the fact that several studies (cited in
Bashore, 1981) have found that a bimanual, bilateral,
symmetrical response produces slower RTs than either a
bimanual or a unimanual response. Bashore concluded that the
processing of a symmetrical bimanual response is very
different to the other two forms of responding.

The problem of intrahemispheric interference due to one hand
being used for both response alternatives can be removed
along with the slow finger syndrome by simply using the

middle finger of each hand to respond appropriately to the
two alternatives.

To summarise, in the present research programme sex of
subject was disregarded. Handedness was controlled to
prevent diluting VF symmetries. Intrahemispheric
interference, along with slow finger or fast hand effects was
nullified or eliminated by using two handed, middle finger
responding and within-subject counterbalancing. S-R
compatibility was also nullified by within-subjects counter-
balancing. All of the within-subjects counterbalancing was
done across the two stimuli using two sessions, sessions
being balanced between subjects. The only between-subjects
counterbalancing was in Experiment 2 where an RBBR/BRRB
counterbalance across conditions was used.

Statistical problems of design and analysis

The discussion of potential response artifacts and their
control indicates that within-subject experimental designs
were the most appropriate approach to the investigative
programme. Also a potential difficulty in obtaining suitable
subjects meant that the economic within-subjects design was
preferred to the between-subjects design. Thus, initially,
an entirely within-subjects design was used.

This decision was taken knowing that within-subjects designs
have some problems associated with them and that the detailed

experimental designs would need to take these into account. The interpretation of the results would also need to be suitably circumspect.

Statistical problems in design

The within-subjects design has a number of statistical problems. Gaito (1961) analyzed these problems and showed that they are of two basic types, one being the way in which order effects influence the F ratio and the second being the impact of correlated measures on the F ratio. He considered several designs but only those designs and conclusions relevant to this programme will be summarised here.

Order effects are inescapable components of any within-subjects linear sum of variance design. All one can do is determine how the associated variance is to be apportioned among the model's terms. This variance can appear in the main effects, interactions or the various error terms, singly or in combination, thereby inflating the terms and consequently biasing the F ratios.

If order effects are controlled by randomised presentation of treatments, the variance appears entirely within the residual error term (Var_e). With Var_e thereby being inflated, F ratios are reduced when order effects are present. If, instead of randomization, treatments are counterbalanced by one group of subjects taking one order and another taking the reversed order, (that is, an inter-subject AB/BA

counterbalance), any variance due to order (Var_o) appears in the Treatment x Subject interaction giving a conservative F test. The balancing equalizes the levels of each main effect and also those interactions that do not contain the order effect. However, those interactions containing Var_o are inflated and this inflation is increased with increasing order of interaction (Gaito, 1961).

Similar conclusions would hold for *intrasubject* counter-balancing, ABBA. That is, Var_o is confounded with treatment variance (Var_t). When both forms of counterbalancing are used, we have the important ABBA/BAAB design. Gaito (1961) points out that if order effects are constant from trial to trial for all subjects, no bias occurs for main effects or interactions but that the within-cell terms will be inflated, giving lower F ratios for interactions containing order. If, however, the order effects vary within- or between-subjects the inflation will be confounded with the interaction terms, thereby biasing the F ratio to an unknown extent.

One other design needs to be mentioned, the simple Latin square where each subject receives a different order of treatments, each order being selected from the set of all possible orders. Here, all possible interactions of treatment, subject and order contribute unwanted variance to all effects. Unless these interactions all have zero variance, the F test may become unreliable.

So, in sum, attempting to control for order effects in within-subjects designs means that the F ratios are invariably biased to various degrees depending upon which terms are inflated by Var_o. Gaito (1961) considers that full randomisation giving valid but conservative F tests is the safest procedure. One can infer from his discussion that a balanced ABBA/BAAB design would also be acceptable provided that constant carryover effects can be assumed or demonstrated. However, not all of the error terms may be inflated and some caution is needed in interpreting results.

The second statistical problem of within-subjects designs is correlation between the repeated measures. Because summary statistics are used for the individual subject entries in the ANOVA cells, within condition correlation has no effect (Hays,1973; p.574). But unless the correlation between conditions is constant and homogeneity of covariance occurs, F ratios will be too high. However, when a variable has only two levels, these requirements are met (divided VF and Stimulus are current examples). When more than two levels are used, homogeneity of covariance is likely to occur when the correlations are not bound to the treatments themselves. That is, the correlations do not depend upon, for instance, whether GP1 follows GP3 rather than GP5 (Lana & Lubin, 1963). In the present programme where the same two-choice RT task is carried out repeatedly under random GP and VF conditions, homogeneity of covariance could be expected to have occurred.

Two plausible sources of heterogeneous covariance would be fatigue and simple practice effects. The effects of both of these sources can be reduced by providing adequate rest periods and giving practice until asymptotic performance has been achieved. Thus, experiments that use two-choice RT tasks performed many times over will be reasonably free from covariance problems. A still further reduction of correlation effects can be achieved by randomisation across conditions (Gaito, 1961). But when conditions differ across occasions, order effects may occur and these must be controlled for methodologically or statistically.

These combined effects of order and correlated measures meant that within the present experimental programme, randomisation was used wherever possible. Where this was impracticable, within-subjects counterbalancing was used in conjunction with between subjects counterbalancing (e.g., an ABBA/BAAB design).

The problems introduced by the above considerations were most evident in Experiment 2 where each subject participated in both blocked and randomized conditions. Under randomised conditions, trials were randomised over both GP and VF. Under blocked conditions, trials were randomised over VF but presented in blocks on each GP in turn. The GPs for each block of trials were chosen randomly with the restriction that each GP was used only twice. Then, within each condition, unwanted order variance would appear in the

residual error term giving a conservative F test. This was quite acceptable.

There was, however, no fully satisfactory solution to the sequencing of random and blocked conditions due to the associated order effects. The problem arose because two sessions per condition were needed to control for S-R compatibility effects, with either randomisation of conditions or counterbalancing of conditions as design options. As previously noted, the safest form of counterbalancing is the combined inter- and intrasubject ABBA/BAAB design where Var_0 appears in the residual term, provided that any order effects are constant from trial to trial. Unfortunately, there was no guarantee of symmetrical carry over between self-paced random trials and experimenter-paced blocked trials so that confounding of interaction and order variance was a possibility.

On the other hand, randomisation of conditions had practical problems. A random sequence of conditions would have required those subjects receiving the same conditions (e.g., RR or BB) for the first two sessions to make two reversals in response finger/stimulus pairings compared to only one for those who received an RB or BR sequence (controlling for S-R compatibility). Thus, conditions for the two classes of sequencing would have differed across subjects and produced increased error variance with an unknown distribution.

Both randomizing and counterbalancing the two conditions were associated with serious problems, but randomisation was considered to be the more so because the unwanted variance would be unevenly distributed across the subjects. By comparison, the Var_o that might result from counterbalancing would only be a problem if it was undetected. Therefore, a within- and between-subjects counterbalanced design was chosen with order being included as a factor in the analysis. Thus, to minimize the statistical problems associated with the sequencing for a within-subjects design, for half of the subjects the conditions for each session were presented in an RBBR sequence. The remaining subjects received the conditions in a BRRB sequence.

Statistical problems of analysis

The analysis posed a number of problems from the very beginning of the programme, most being a consequence of individual variability. Laterality studies are notorious for nonreplicability. Almost as notorious is the fact that, often, only a few of the subjects used in an experiment actually show the VF advantage that is reported for the experiment. Most researchers avoid this problem by using large numbers of subjects rather than large numbers of trials as did Sprott and Bryden (1983). These authors illustrated the problem with data from one of their experiments. Using 16 subjects, an overall RVF advantage was found ($p<0.05$) but considered individually, only three subjects showed a significant RVF advantage while one even had an LVF

advantage. Raising the *alpha* level to 0.25 would have added only one further subject to those giving an RVF advantage.

Levy (1983) has considered the problem of the relationship between group and individual performances with respect to laterality indices. She notes that studies that use summary statistics obtained from representative groups suffer from some severe interpretive difficulties. In particular, even if group differences are real, individual variations are meaningful because they can represent different cerebral organization or, alternatively, insufficient reliability and validity of the measures that are used.

In Andreasen (1988), 75% of the total variance was due to individual variability which meant that small experimental effects could easily be lost in the background noise. The corresponding figures for the present programme were comparable; almost all studies had individual variability accounting for 75% or more of the variance. Consequently, different ways to increase the sensitivity of the experiments were used. The obvious ones, such as the experimental control of posture, of cognitive strategy, and S-R compatibility have already been described. An alternative approach that was considered was to remove the noise variance *post facto* by conducting the analysis using difference scores.

Difference scores

In the present programme, interest centred on whether or not an eye movement away from the central rest position affected RTs compared to the centre GP; the centre GP thus had no value other than to act as a reference position. Hence, if the centre GP were to be considered as a baseline measure, all unwanted variance could be removed by subtracting RTs on the centre GP from those on the peripheral GPs. A similar method is used in electrophysiological studies (Guthrie & Buchwald, 1991; Samar, 1983). Unfortunately, there are both conceptual and statistical problems associated with using difference scores in this way.

Conceptually, GP difference scores are not the same thing as difference electrical potentials. EEG potentials are the immediate consequent side effect of an ongoing process and are used to track the time sequence of the processes of interest by identifying the relevant time intervals. That is, the difference scores serve as markers. However, in the present study, GP difference scores are used as process measures. Furthermore, it is assumed that the measured RTs are the end result of a processing sequence; so the difference scores serve to indicate that a different processing sequence has occurred. This may not be the case and it is incumbent upon the experimenter to demonstrate that a different process *has* occurred before using difference scores. Levy (1983) has made very similar comments in respect of the use of laterality indices, which, in the main,

are variations of difference scores. Assuming that RT difference scores indicate different processes is therefore a doubtful procedure. Even if different processes could be assumed, difference scores are contraindicated by reliability considerations.

The reliability of difference scores are found by dividing the variance of the difference score by the total variance. In the present instance the numerator is given by the sum of the variances of the two GPs minus twice their covariance; the denominator is given by the sum of the numerator plus the error variance for the two GPs (Donaldson, 1983; Levy, 1983). With this expression, the higher the (positive) correlation between the two component scores the lower the reliability of the difference. For the experiments reported in this programme, the individual correlations between GPs can be presumed to be fairly high with a concomitant reduction in reliability of the difference scores. This is an important point because, as is well known, the reliability of a test increases as the number of items or trials increases. Levy quotes published data to show that in one experiment with 120 trials a test-retest reliability of 0.7 was found on two separate occasions. A similar experiment with 58 trials per session gave a reliability of only 0.36. The present programme had only 26 trials per condition in each of two sessions. Although test-retest coefficients were not calculated, visual inspection of the raw scores revealed that the reliabilities were very low. Hence, difference scores

would have had an even lower reliability. In other words, had difference scores been used, experimental effects would have been more likely to have been lost in the individual variance compared to using the raw scores. A test analysis using difference scores showed that this was in fact the case.

RT analysis

Sprott and Bryden (1983), writing about cerebral laterality indices, offer a suggestion that is relevant to the problem of isolating performance changes against a noisy background. They suggest that individual RT distributions should be incorporated into the analysis. Unlike summary statistics, such as the mean or median, this procedure uses all of the available information and can lead to novel interpretations of the data. They recommend that the entire RT distribution for each subject should be inserted into the normal ANOVA. RT distributions, however, typically have a large positive skew which violates the assumptions of the ANOVA procedure. The recommendation as offered is therefore simplistic and unsuited for RT data. However, the basic idea has considerable merit, provided that a suitable analytical method can be found.

One well developed method for RT distribution analysis is to fit the data to a probability density function, extract the parameters of the function, and insert them into the ANOVA. At present, one of the density functions that provide a good

match to the typical RT distribution is the ex-Gaussian, formed by the convolution of the exponential and Gaussian functions (Heathcote, Popiel, & Mewhort, 1991; Ratcliff, 1979). The ex-Gaussian distribution is characterised by three parameters that can be used in place of the usual mean and variance parameters of the normal distribution, and which can be entered into their respective ANOVAs.

The major advantage of using the ex-Gaussian distribution is that all of the individual data are used, including outliers that are otherwise often discarded before analysis. The disadvantage of the ex-Gaussian is that about 100 trials in each condition are needed to produce stable estimates of the parameters. Thus, when subjects are required to serve in several conditions, as in the current programme, the demands on them become unacceptable. When individual trial numbers per condition are too few, Vincent averaging over the subjects (Ratcliff, 1979) can be used to estimate the group parameters. Unfortunately, this procedure precludes the use of inferential statistics because the procedure produces only one estimate for each of the three parameters, these being the *group* parameters. Therefore, distributional analysis could not be used to increase the sensitivity of the experiments in the present programme.

Summary statistics

Being unable to use distributional analysis was doubly disappointing because to have done so would have removed the problem of how to deal with outliers. RT data are almost always skewed, the skewness arising from one of two sources. Either the skewness is generated by the process of interest, or it is due to noise, such as inattention, fatigue and so on. Regardless of the source, skewness has the effect of violating the normality assumptions of most parametric analyses. This means that unless distribution analysis is to be done the skewness must be removed or reduced to acceptable levels before proceeding with the analysis.

Rescaling the data by a mathematical transform is one way to remove the skewness; the logarithmic transform is often used for this purpose. Another way to remove skew is to trim the data. That is, RT values above an arbitrary cut off point are disregarded. However, while rescaling and trimming may solve a statistical problem it raises a semantic one (Heathcote et al., 1991). To trim or normalize the data is to assume that the skew is mainly due to nuisance variables. If this assumption is wrong, how meaningful is the resulting measure of central tendency when the skew has been removed? Also, how does this affect the researcher's interpretation of the data? Furthermore, how does one know whether or not the skew is due to noise without doing a distribution analysis?

Normalizing or trimming the data in the present studies was clearly undesirable from an investigative viewpoint. At the same time this still left the problem of how to deal with outliers which have a disproportionate affect on the sample mean. One could have chosen to ignore the possibility that the skew was due to underlying processes and used trimmed data. But with a maximum of only 26 trials per condition, one or two extreme outliers could markedly affect the analysis. Some of the distributions from Andreasen (1988) were used to see what the effect of trimming would be. After dropping error trials and setting the cutoff at two standard deviations, sample means were sometimes being estimated from as few as 10 trials, clearly an unacceptably low number. It can also be noted that a more rigorous simulation has shown that trimming the data has the effect of underestimating the population mean by an amount that depends upon the sample size and variance of the sample (Miller, 1991).

The alternative to using the mean was to use median RTs instead. The median is not as susceptible as the mean to the effect of outliers, and using the median does not entail any assumptions about the distribution. One can also be quite certain that half of the observations lie above and below the measure. Unfortunately, the median also has its drawbacks. Whereas trimmed data give an under-estimate of the sample mean, the median of skewed data over-estimates the population median, the over-estimate varying inversely with sample size. The bias thus introduced is exacerbated when making

comparisons across conditions with unequal trial numbers (Miller, 1988). Fortunately, the bias is minimized when medians are derived from the same or nearly the same number of trials and also when the number of trials per condition exceeds about 20. A random sample of distributions from the first experiment of the present programme showed that a fairly stable estimate of the median could be made when the sample exceeded 15-20 trials.

It can be seen, then, that there was no satisfactory answer to the problem of outliers, let alone individual differences and variability. RT distribution analysis would have solved many problems but was impracticable since it would have made unacceptable demands upon the subjects. With difference scores having been rejected, the statistical questions boiled down to: what summary statistic, mean or median, was to be used in a standard ANOVA? The median was ultimately chosen for the following reasons: It had already been shown that a stable estimate could be made using 20 or more trials. Using trimmed data would result in too few trials for stable estimates of the means. Also, with less than 26 trials, the effect of outliers on untrimmed data was expected to produce large and variable over-estimates of the means compared to a small under-estimate of the medians.

Alpha and *Omega*

To determine whether or not an experimental manipulation has had any effect, the mean outcome when the manipulation is

operating is compared to the mean outcome when it is not. Expressed differently, the decision is, "do these two means come from two different distributions or do they come from just one distribution?"

When an experimenter decides whether or not an experimental manipulation has had any effect the decision is based upon the probability that the observed outcome was due to chance factors alone. The decision rule is simply to say, "If the probability of this being a chance outcome is less than X then the manipulation was effective". This predetermined probability "X" is called the *"alpha"* level, and is usually set at 0.05. Naturally, the more variable the scores that were obtained as a result of the manipulation the more difficult it is to decide that there was some effect. Also, the less the variability due to other causes, the more effective the manipulation will be; alternatively, it will be easier to detect. Consequently, it becomes important to minimize the variability of the observed scores. Having decided that the manipulation was effective, the next question that arises is "how effective was it?" To answer this question, the variability of the scores that can be attributed to the manipulation is calculated, often as a percentage of the total variability. One measure that is often used is w^2 (Hays, 1973). Keppel and Zedeck (1989) give several ways of obtaining estimates of w^2; for the present study the ratio between the ANOVA Mean Square (Effect) to the sum of Mean Squares (Experimental Effects) was used. When

expressed as a percentage this ratio gave an estimate of the Experimental variance accounted for; including the Subject Mean Square in the denominator gave an estimate of the Total variance accounted for.

The importance of attempting to reduce the effects of individual variability on the analyses can readily be seen when w^2 and the significance levels for the experiments are considered (Table 14 below); w^2 is shown as a percentage of both total and experimental variances. For illustrative purposes, only the horizontal components of each condition in the first four experiments are listed. Experiment 5 is excluded because of the reservations regarding possible S-R compatibility effects. Also shown are the subject variances which range from 62% to 84% of the total variance with a mean of 73%. The subject variance figures are similar those of Andreasen (1988).

A consequence of such a high level of individual variability is that detecting real experimental effects requires more than simple significance testing. Small but real effects can easily be concealed by the individual variance. In other words, high subject variance reduces the sensitivity of the experiment. In such a situation, setting a strict alpha would fail to detect any real effect while a lax *alpha* could collect a lot of spurious ones. Furthermore, relying solely on *alpha* could be misleading.

Table 14. Comparisons of *Alpha* and w^2 for the horizontal GPs of Experiments 1, 2, 3 and 4. w^2 is shown as a percentage of both the total and experimental (Expt) variance.

		Random Variance (%)			Blocked Variance (%)		
Expt	Effect	Total	Expt.	*Alpha*	Total	Expt.	*Alpha*
E1	Subj.	83.6					
	GP	0.3	1.8	0.50			
	VF	2.4	14.5	0.15			
	GP*VF	0.6	3.9	0.005			
E2	Subj.	81.9			78.6		
	GP	1.4	7.5	0.21	1.9	8.7	0.20
	VF	1.7	9.0	0.15	6.5	30.3	0.10
	GP*VF	1.8	10.0	0.065	0.14	0.7	0.70
E3	Subj.	64.3			77.6		
	GP	1.2	3.3	0.25	4.5	20.0	0.05
	VF	22.6	63.4	0.01	4.6	20.3	0.12
	GP*VF	0.7	2.0	0.60	0.2	1.0	0.80
E4	Subj.	57.4			71.6		
	GP	0.2	0.5	0.8	1.9	6.7	0.40
	VF	30.6	71.8	0.005	12.3	43.2	0.01
	GP*VF	1.5	3.6	0.25	2.0	7.0	0.09

It is often assumed that the importance of a relationship, or confidence in a result, can be judged from the *alpha* level alone. But this assumption is incorrect (Eysenk, 1960; Lykken, 1968) and can be illustrated by examining the

contents of Table 14. There it can be seen that the *alpha* values often do not follow any discernable pattern. For example, the VF main effect which was expected to be consistently evident produced only three significant *alpha* (0.05) values out of seven occasions on which it was assessed. However, patterns can be discerned when the w^2 values are examined. Consider the w^2 values for VF; on five occasions they are the largest experimental effects and are effectively equal largest on a further two occasions. The impact of this was that a highly significant VF effect was found when all experiments were analyzed together.

Although not as obvious, the w^2 values for the other effects also follow patterns corresponding to the significant GP and GP x VF interactions that appeared in the meta analysis. On two out of two occasions the blocked GP effect had a higher w^2 value than the GP x VF interaction with the values being similar on the third instance. Conversely, the randomized GP x VF interaction had the higher value two out of three times. While w^2 appears to be rather more informative than *alpha*, it also can be misleading when considered in isolation. For instance, in the R condition of Experiment 3, w^2 for the GP effect was higher than that for the GP x VF interaction. However, the RT values (Table 6; p. 118) show that an interaction cannot be entirely ruled out, especially when considered together with the first two experiments. Thus, in addition to *alpha* and w^2, the actual RTs must be used when evaluating the results of these or any other experiments.

The essential feature of the RTs is that over the first three experiments, they reveal three instances of similar crossover interactions under randomized conditions and two similar GP main effects under blocked conditions. That is, consistent replications were found even though not all were statistically significant, or had a relatively large w^2.

Rejecting interesting results by relying too heavily on a strict statistical criterion is but one side of the coin. The other side is, that by accepting every significant effect, spurious or irrelevant effects can cause undue complications when interpreting the results. This happened with Stimulus effects in Experiment 3 of the present programme, and some considerable effort was needed to contain their impact on the interpretation of the main results. A statistical purist would probably say that if an effect is significant then you must accept it, regardless of the interpretive problems that it may cause. However, such an approach may have clouded the issues sufficiently to have lost the interesting GP effect that was found. In this case, pragmatism and the Dunnet test were more appropriate to the programme requirements.

The importance of using multiple criteria when accepting or rejecting effects, becomes even more apparent when the statistical power of an experiment is examined. Consider the GP effect that appeared under B conditions in the meta analysis. This effect was significant at $p < 0.01$ and w^2

accounted for 13.06% of the experimental variance, or 2.70%
of the total variance. Using the latter value, a simple
calculation (Keppel, Saufley, & Tokunaga, 1992) shows that
with 22 subjects contributing data, the power of the combined
experiments was only about 0.15. In other words, with 22
subjects, that result would be expected to occur about once
in every six or seven experiments. Considered another way,
to have an even chance of getting the same result (50%
statistical power) would require 56 subjects.

The purpose of this part of the discussion has been to show
how interesting results can be lost by allowing scientific
judgement to be usurped by blind adherence to arbitrary
statistical rules, especially the shibboleth of the 5%
significance level. Adherence to this rule has been attacked
repeatedly (e.g., Greenwald, 1975; Hays, 1973; Keppel et al.,
1992; Plutchik, 1983) with possibly the most cogent reasons
for its abandonment coming from Eysenk (1960).

Eysenk (1960) pointed out that the term "significant" was
used in two ways: to express the probability of disconfirming
the null hypothesis and to dichotomize the probability
continuum into a significant portion and an insignificant
portion. The first usage is redundant and gives less
information than the original statement of the probabilities.
It also leads to expressions such as "almost significant" or
"approaches significance", which indicate that the verbal

dichotomy is inadequate. Eysenk's solution to this is to abandon the verbal scale and use only the probability scale.

The second usage of "significant" imports additional meaning to the term by commonly dividing successful from unsuccessful research and implying reproducibility of results. Since the only proof of reproducibility is replication, both accretions can be seen to be **subjective** evaluations made by the researcher but mistakenly given **objective** status. Eysenk (1960) argued that the correct procedure is to separate clearly the objective probabilities from the subjective evaluations of the results and justification of the conclusions. Eysenk's position is nicely summarized by his concluding comment that:

> "Subjective judgements of reproducibility cannot reasonably be based on the mechanical application of a rule of thumb whose only usefulness lies in the elementary instruction of undergraduates lacking in mathematical background; if they are to be made at all they demand complex consideration of *a priori* probabilities." (p. 271).

Avant et al. (1993) took a similar approach to reproducibility and significance levels by disbelieving any significant effects that they could not replicate using the same group of subjects. In a novel extension to using replicability as the criterion for acceptance, they used within-subject replication to determine whether or not interhemispheric communication had occurred. The approach

taken in the present programme was similar but here the replication attempts were spread over different studies.

Other problems

Practice effects

The question of reproducibility and noise variance impacts upon another analytical consideration, that of practice effects. One possibility that needed to be examined was that, with extended practice, task performance might become so proficient that GP effects might disappear. This would have reduced the magnitude of the effects that were finally observed. If this occurred then split half analyses should reveal a relatively strong effect in the first half of the trials but little or no effect in the second half. However, a split half analysis revealed a number of intractable problems.

The first problem was that with only 26 trials per condition in each session, the medians for each session would generally have to be estimated from no more than 13 trials. Often there were fewer trials because error trials were discarded. It had already been established that at least 15, preferably 20, trials were needed to give a stable estimate of the median, so any split half analysis would have increased the individual variability to an unknown degree.

The second problem was choosing among the different ways in which the split could be made. The difficulties of this were compounded by the fact that the splits for the R and B conditions were unavoidably different. There were no real statistical problems associated with splitting the R trials. Either the first 13 trials from each GP were selected or the trials from the first half of each session were taken. Because the trials were randomised, the two methods would be expected to partition the trials in almost identical ways. In contrast, the blocked condition can be split in three legitimate ways, each giving very different estimates of the medians and none being strictly commensurate with the randomized splits.

It will be recalled that under B conditions each GP, from a total of five, was selected twice in each session. This was achieved by randomly selecting (without replacement) a number between one and ten. This meant that the same GP could appear twice in succession, and consequently might appear twice in either the first half or the second half of each session. In that case, a second GP would have to appear twice in the other half of the session. The fact that the GPs could be unbalanced between the first and second half of a session was the source of the difficulties in carrying out split half analyses for the B condition.

The simplest split is between the first and second half of each session. But because the sequence of the GPs were

randomised for each subject, it was possible for one GP to be chosen twice in the first half of the session and consequently to make no appearance in the second half. It would perforce be replaced by a second GP appearing solely in the second half of the session. There was a better than even chance of this happening. Such a situation would have resulted in empty cells and unequal Ns in the analysis.

A second way of splitting the data is to select the first occurrence of each GP to comprise the first half of the trials. The uneven distribution of GPs between the first and second halves of the session meant that for a given subject, some GPs taken from one half of the session were influenced to a different degree by fatigue and practice effects than those from the other half. One cannot assume that fatigue and practice effects cancel one another because practice may involve a change of strategy, possibly induced by fatigue.

The third manner of splitting the trials is to take the first half of each block regardless of which half of the session in which it appeared. This method minimizes the differential affects of fatigue and practice but reintroduces the problem of unstable estimates due to too few trials within a condition. Although most of the problems of splitting the trials could have been avoided by balancing the first and second halves of the blocked sessions this would have reintroduced the statistical design problems that were described earlier (p. 196).

When ANOVAs were carried out using the various methods of splitting the trials, the outcomes were so variable both within and between splitting methods that the endeavour was abandoned as being an exercise in futility.

Experimental measures

Two other topics deserve to be considered under the rubric of design problems: choosing between RT and accuracy as the dependant variable, and choosing between CVF and bilateral stimulus presentation.

While there is controversy (Pachella,1974; Sanders, 1980; Santee & Egeth, 1982) as to whether or not RT and accuracy tap the same underlying cognitive processes, this question was of little interest in designing the present experiments. There were two requirements that the dependant variable had to satisfy: to restrict the subjects' opportunities to vary their processing strategies, and to be sensitive to small changes in the performance of simple tasks. Without demands for speedy responding, using accuracy as the measure would not have restricted sufficiently subject's processing strategies. Also, just 26 trials per condition was not enough to assess accuracy with sufficient resolution.

The final choice to be made when designing the programme was between CVF and bilateral stimulus presentation; both methods ensure that the two hemispheres have equal access to the stimulus information. Here, the interest lay in comparing

the performances of the cerebral hemispheres when only one had direct access to the stimulus to performances when both had equal access to the stimulus. CVF presentation assumes that innervation from the fovea projects equally to left and right hemisphere. The truth of this assumption is not certain for humans, but it has been established that a medial strip, about one degree wide, projects to both hemispheres in both the cat and the monkey (Bradshaw & Nettleton, 1983). This is contradicted by psychological evidence from humans. Simple RT using an interhemispheric transmission time paradigm gave no evidence for overlapped innervation at the fovea (Harvey, 1978; Lines & Milner, 1983). However, the validity of the method used to assess the transmission time is questionable (Hasbroucq, Kornblum, & Osman, 1988) and so the electrophysiological and anatomical evidence from the monkey was accepted as being more reliable. The disadvantages of CVF presentation are that the stimulus quality is different to that of unilateral presentation in one VF. Also, if the stimulus extends beyond the region of overlapped innervation, then integration of information across the midline is required. Bilateral presentation would have equalized the stimulus quality between unilateral and bilateral trials and no integration of information would have been required. At the same time, CVF presentation was expected to act as an added form of fixation control, in a manner similar to those studies that require subjects to report on a digit presented in the CVF. Furthermore, provided that the stimuli did not subtend more than about one

and a half degrees at the fovea then CVF presentation would be more naturalistic than bilateral presentation. Also, acuity gradients due to retinal eccentricity across the stimulus would be both symmetrical and of lesser magnitude with CVF presentation.

Mistakes

When the programme was being designed, the choice between bilateral and CVF presentation seemed to be more a matter of convenience than anything else and concerns about fixation tipped the balance in favour of CVF. In retrospect this was probably a mistake. Had more attention been paid to the wider theoretical views of cerebral laterality, especially the notion of independent resource pools, bilateral presentation would have been used. By doing so, each hemisphere would have been forced to operate independently of the other (Bradshaw & Nettleton, 1983) whereas with CVF presentation hemispheric interaction may have occurred, possibly giving unclear results.

A more serious mistake was attempting to include too many levels of the independent variables into one experiment (e.g., Cohen, 1990). The extreme example is Experiment 2 where each subject served in four sessions. The demands upon this group were excessive and gave scheduling and motivational problems. Consequently, the results were not as clearcut as they might have been. Despite changing to a

between-groups design, this same mistake can now be seen to have occurred in the other experiments. Using up to 780 trials per session was rather excessive, and was due to including both vertical and horizontal GPs in one experiment. This in its turn was due to deciding to use a within-subjects design, or to maximize the within-subjects contribution when separate groups were used. Nothing would have been lost by separating the vertical and horizontal GPs into different experiments and much could have been gained. Shorter sessions would have reduced the fatigue and motivational problems, and possibly allowed more subjects to have been used. Conversely, more trials in each condition could have been used giving a more stable estimate of the median. More importantly, shorter sessions with fewer levels of factors allowing more subjects to be run would have increased the sensitivity of the experiments and given an increase in statistical power. Both increased sensitivity and increased statistical power are highly desirable when only small effect sizes are expected.

The most serious mistake in the entire programme was to change the stimuli in the final experiment. Originally, subjects were to decide upon the symmetry or asymmetry of a random dot and line array presented at different angular orientations (Corballis & Roldan, 1975). The logic for this choice was that mental rotation would be a difficult visual task and the differing angular orientations would give a scale of task difficulty. Unfortunately, the details were

not worked out until the experiment was about to be organised when it was found that over 3000 trials per session would be required. This was clearly unacceptable and so the cartoon face was devised as an alternative and the potential impact of S-R compatibility was completely overlooked. It appears that a mental set in favour of a mental rotation task had developed! Had this preoccupation with mental rotation not existed, some other task that used primarily visual-spatial processing would have been used. The square arrays with dots within them, as used by Casey (1981), would probably have been used. Since these stimuli would have had few S-R compatibility properties the results would have been more readily interpreted.

One final mistake should be noted. This was to substitute head turning for the blocked condition, rather than running it as an extra condition. This decision was made before the meta analysis was done and was based on the belief that there were no consistent differences across studies between the blocked and randomized conditions. Omitting the B condition prevented one knowing for sure whether or not the study was contaminated by S-R compatibility effects. If it was contaminated, the GP effect found when using verbal stimuli should have appeared in the blocked condition.

These mistakes have taught the author some hard-learned lessons. A good experiment should be very tightly focused with the bare minimum of manipulations and levels of the

independent variables (Cohen, 1990). Deviations from the design details should be made only if forced by circum-stances and then only after very careful consideration. At the same time, equal attention should be given to both the details of the investigation and the wider theoretical issues to which it is linked. Also, even though the experimenter has a vested interest in the experiment, subjects definitely do not and this aspect of human intransigence must be allowed for in the design stages.

Future research

The programme of research that has been described here produced evidence for two interesting phenomena: an unexpl-ained effect of deviated gaze position when verbal stimuli are used and an intrahemispheric interference effect involving eye movements. Obviously, both effects require independent replication, preferably using rather more difficult tasks in an effort to increase the magnitude of the effects. In fact, first priority should be given to increasing the size of the effects and reducing noise variance (i.e., increased statistical power) which could well be done within the framework of RT distribution analysis. Two approaches suggest themselves: If the number of conditions were to be reduced by separating the vertical and horizontal GPs and dropping the CVF presentation, an intensive investigation of a few subjects could be made including their performances in a standard CLEM experiment.

Alternatively, using say 40 subjects and Vincent averaging (Ratcliff, 1979) over groups of four, the advantages of RT analysis and inferential statistics could be combined. This technique would allow CVF or bilateral presentation to be retained.

If the GP effect is due to a bias to one or the other hemispaces, then a comparison between strongly left handed and strongly right handed groups should produce GP effects to left and right according to handedness. Alternatively, combining deviated GP with induced OKN (Rosenberg, 1980) may allow hemispace bias to be manipulated to varying degrees. The suggested link between saccades and subvocalization should be investigated, possibly by interfering with subvocalization using tasks with differing degrees of verbal content. More elaborately, if subjects with left hemisphere voice control can be distinguished from those with right hemisphere, then GP effects should differ between the two groups. With the interference effect being associated with eye movements, further work could well be linked to saccade initiation and control. One more point can be noted; applying the reverse CLEM methodology to early processing stages (Avant et al., 1993; Christman, 1990) might extend the investigation of meta control or help to establish the locus of the GP effect.

In retrospect this programme did not open up vast vistas of unexplored territory. Nevertheless, a few modest achieve-

ments can be claimed. Hopefully, Kinsbourne's attentional gradient theory can now be laid to rest. Certainly, the present multiple failures to support it complements Boles' (1979) multiple failures to replicate. The evidence also appears to add support to the idea of intrahemispheric interference (Green, 1984). Finally, the reverse CLEM methodology proved to be sufficiently viable to uncover an interesting GP effect and, using randomized and blocked GPs, to differentiate between the effects of continual movements and a steady gaze.

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Appendices

List of abreviations

This list of abreviations is used in one or another of the following appendices.

```
Centre visual field..................CVF
Condition...................Cond, Con, C
Experiment................Expt, Exp, E
Gaze position........................GP
Hand.................................H
Left visual field....................LVF
Order................................O
Right visual field...................RVF
Session..................Sess, Ses, Se
Stimulus.................Stim, Sti, St
Subject...............Subj, Sub, Su, S
```

Notes

Because of the large number of factors used in the ANOVAs, in a few ANOVA tables, the entries for some effects occupy two lines and are indicated by indentation of the second line.

In all ANOVA tables the probabilities are given only if $p < 0.1$

Appendix 1

Control and timing of the stimulus exposure

The roll-over cycle of the VDU frame was used to control the duration of the stimulus exposure. The frame was written in from the top of the screen with a roll-over time of 16.67 msec which gave a lapsed time of 50 msec (stimulus duration) for three frames. The timer was synchronized with the top of the VDU frame *via* the video controller and all timing was taken from this point. Closing the external trigger tripped the timing of the frame onset. After 8 msec, when the frame had reached its midpoint, the stimulus was written in. Two and a half frames later at the top of the frame, the mask was written in and intersected the stimulus half a frame, or 8 msec, later. The stimulus was thus exposed for 50 msec. Because the timing was started at the top of the frame and the stimulus exposure lagged by 8 msec, the recorded RT was composed of the overall elapsed time from the top of the starting frame to the mask offset, less the 50 msec of stimulus exposure and the 8 msec lag. Estimated as a proportion of frame time, the 1 cm stimulus occupied about 1 msec, thus the stimulus onset and masking error times were approximately 1 msec each. All critical time sequences con- trolled by the computer were independently checked by an external timer (made in the Massey University Psychology Department workshop) that was accurate to 10^{-4} s.

Appendix 2

Stimulus list for Experiment 3

Words

```
ADD AID AIM ALL AND ANY ARE

ATE BAD BUT BUY CAN DID FEW

FOR GET GOT HAD HAS HIM HIS

HOW ITS LAW LED LIE LOW MAY

NOT NOW OFF OUR OUT OWN PAT

PUT RAP SAD SEE THE TWO VOW

WAS WAY WHO WHY WON YET YOU
```

Non Words

```
AIS AOM AOW ALC ANC ANS ARU

ASE BES BRY CUN DUT FEF FOH

GAX GEX GID GOK HAF HIG HUD

HUS LAL LOD LIF LON MIY NOF

NOY OMF OTS OUB OUG OWY PAF

PIV RAL SEN SME TOB TRO VOB

VUT WAB WIO WOB WUY YED YOI
```

Appendix E1

Experiment 1

Table 1. Individual mean median RTs (msec) sorted by Session, GP, VF, Stimulus, and Stimulus/Response hand combinations. Subjects A-E used Left hand/respond X in the first session, F-J used Right hand/respond X.

		LVF									
		GP1		GP2		GP3		GP4		GP5	
Sub	Ses	X	V	X	V	X	V	X	V	X	V
A	1	460	482	457	470	447	475	436	483	484	489
	2	482	433	458	434	483	428	485	426	468	461
B	1	324	361	304	358	318	370	309	360	325	363
	2	352	303	327	301	314	307	336	319	326	325
C	1	488	485	451	481	380	480	405	478	445	470
	2	445	413	469	432	461	388	466	397	464	415
D	1	423	408	399	396	359	406	395	401	411	414
	2	401	397	395	393	402	405	393	394	422	404
E	1	348	397	384	432	349	427	356	407	379	433
	2	387	361	374	356	414	350	393	388	426	375
F	1	570	510	556	524	563	492	575	540	577	454
	2	467	545	486	546	538	560	530	515	524	565
G	1	395	392	400	402	377	431	388	398	396	404
	2	413	396	386	382	384	394	408	371	394	399
H	1	534	452	494	418	554	451	508	453	538	450
	2	399	446	407	482	406	455	388	466	394	442
I	1	432	375	439	362	427	421	439	440	430	374
	2	400	405	386	408	379	413	366	408	363	413
J	1	391	337	364	336	380	309	385	330	382	340
	2	329	364	334	379	312	360	320	350	329	372

(continued)

Table 1 (continued)

Sub	Ses	RVF									
		GP1		GP2		GP3		GP4		GP5	
		X	V	X	V	X	V	X	V	X	V
A	1	478	402	460	398	474	426	497	435	518	421
	2	422	470	436	468	417	459	424	444	451	479
B	1	345	312	328	301	339	314	333	309	343	306
	2	287	329	279	334	286	338	294	323	299	333
C	1	511	435	492	437	489	464	469	461	487	410
	2	418	430	379	426	405	439	407	443	446	432
D	1	421	382	443	376	411	369	443	383	416	381
	2	363	426	341	427	351	409	347	438	367	429
E	1	408	376	411	394	400	400	408	387	430	388
	2	351	427	367	410	437	391	387	369	442	396
F	1	544	529	508	505	492	525	496	527	572	536
	2	494	511	511	525	503	500	540	493	503	497
G	1	341	462	329	454	352	455	337	444	349	446
	2	410	351	428	340	420	362	457	375	423	370
H	1	392	498	405	519	406	496	417	487	414	522
	2	458	412	435	413	469	413	443	402	469	421
I	1	433	463	371	463	378	471	459	465	393	473
	2	452	343	410	369	417	423	421	384	435	367
J	1	326	358	340	381	345	348	341	356	335	348
	2	335	298	315	369	319	347	326	355	326	350

Table 2.   ANOVA: Hand x (Session x GP x VF x Stimulus).

Source	df	SS	MS	F	p
Hand	1	50153.602	50153.602	0.35	
Sub*(H)	8	1149722.459	143715.307		
Session	1	26748.602	26748.602	16.72	0.005
H*Se	1	742.562	742.562	0.46	
Sub*Se(H)	8	12796.260	1599.532		
GP	4	3385.625	846.406	3.19	0.05
H*GP	4	1816.485	454.121	1.71	
Sub*GP*(H)	32	8495.640	265.488		
VF	1	1887.902	1887.902	1.40	
H*VF	1	3.062	3.062	0.00	
Sub*VF*(H)	8	10805.260	1350.657		
Stimulus	1	311.522	311.522	0.41	
H*St	1	602.702	602.702	0.79	
Sub*St*(H)	8	6094.500	761.812		
Se*GP	4	1072.584	268.146	1.02	
H*Se*GP	4	856.125	214.031	0.82	
Sub*Se*GP(H)	32	8400.239	262.507		
Se*VF	1	1.102	1.102	0.00	

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
H*Se*VF	1	155.002	155.002	0.23	
Sub*Se*VF(H)	8	5469.619	683.702		
Se*St	1	2.722	2.722	0.00	
H*Se*St	1	951.722	951.722	0.16	
Sub*Se*St(H)	8	47464.779	5933.097		
GP*VF	4	504.884	126.221	0.62	
H*GP*VF	4	887.925	221.981	1.09	
Sub*GP*VF(H)	32	6513.839	203.557		
GP*St	4	3408.065	852.016	2.57	0.06
H*GP*St	4	674.884	168.721	0.51	
Sub*GP*St(H)	32	10588.200	330.881		
VF*St	1	1085.702	1085.702	3.30	
H*VF*St	1	4935.062	4935.062	15.02	0.005
Sub*VF*St(H)	8	2629.259	328.657		
GP*VF	4	32.485	8.121	0.02	
H*Se*GP*VF	4	3176.484	794.121	2.05	
S*S*GP*VF(H)	32	12422.680	388.208		
Se*GP*St	4	2619.065	654.766	1.81	
H*Se*GP*St	4	2213.764	553.441	1.53	

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
S*Se*GP*St(H)	32	11559.320	361.228		
Sub*Se*					
VF*St(H)	8	15230.900	1903.862		
GP*VF*St	4	884.185	221.046	1.09	
H*GP*VF*St	4	1042.025	260.506	1.29	
Sub*GP*					
VF*St(H)	32	6478.640	202.457		
Se*GP*VF*St	4	1082.064	270.516	1.50	
H*Se*					
GP*VF*St	4	691.985	172.996	0.96	
Sub*Se*GP*					
VF*St(H)	32	5779.199	180.600		
Total	399	1579648.937	3959.019		

Table 3. ANOVA: GP x VF x Stimulus, collapsed over sessions.

Source	df	SS	MS	F	p
Subject	4	39477.857	9869.464		
GP	4	2904.973	726.243	0.05	
Sub*GP	16	243102.593	15193.912		
VF	2	93.923	46.961	0.03	
Sub*VF	8	14705.793	1838.224		
GP*VF	8	5148.826	643.603	0.46	
Sub*GP*VF	32	44388.456	1387.139		
Stimulus	1	39.015	39.015	0.15	
Sub*St	4	1050.676	262.669		
GP*St	4	1935.093	483.773	1.94	
Sub*GP*St	16	3985.173	249.073		
VF*St	2	194.170	97.085	0.62	
Sub*VF*St	8	1251.113	156.389		
GP*VF*St	8	2015.846	251.980	1.58	
Sub*GP*VF*St	32	5112.536	159.766		
Total	149	5406.048	36.282		

Table 4. ANOVA; GP x VF.

Horizontal GPs

Source	df	SS	MS	F	p
Subject	9	181380.650	20153.406		
GP	2	114.408	72.204	1.20	
GP*Subj	18	1086.675	60.371		
VF	1	570.417	570.417	2.43	
VF*Subj	9	2111.000	234.556		
GP*VF	2	305.308	152.654	7.51	0.005
GP*VF*Subj	18	365.775	20.320		
Total	59	185964.233	3151.936		

Vertical GPs

Source	df	SS	MS	F	p
Subject	9	191180.204	21242.245		
GP	2	114.408	72.204	3.22	0.07
GP*Subj	18	1027.500	57.084		
VF	1	561.204	561.204	3.20	
VF*Subj	9	1576.004	175.112		
GP*VF	2	13.358	6.679	0.16	
GP*VF*Subj	18	767.308	42.628		
Total	59	195492.746	3313.436		

Appendix E2

Experiment 2

Table 1. Individual median RTs (msec) as a function of session, condition, GP, VF and stimulus. Subjects A-E received a BRRB sequence, subjects F-J received an RBBR sequence.

		LVF									
		GP1		GP2		GP3		GP4		GP5	
Sub	Order	X	V	X	V	X	V	X	V	X	V
A	B	328	358	316	364	365	354	323	317	339	359
	R	334	334	329	361	296	342	321	309	327	329
	R	305	355	311	370	330	364	294	340	306	364
	B	309	310	330	339	333	319	326	340	321	341
B	B	436	423	424	392	442	467	429	395	425	406
	R	402	392	448	371	394	394	423	373	405	409
	R	429	419	421	392	470	506	430	387	416	450
	B	432	430	426	410	440	438	436	409	437	427
C	B	380	364	424	374	390	334	392	370	409	400
	R	332	392	315	351	296	353	297	324	321	340
	R	391	372	380	338	384	362	362	338	404	329
	B	358	383	331	384	356	398	327	333	342	387
D	B	383	442	412	461	419	445	450	459	434	461
	R	403	386	397	381	419	406	436	390	411	387
	R	383	386	380	398	382	420	346	416	384	440
	B	405	424	408	404	418	411	404	412	423	385
E	B	466	445	435	364	452	395	447	460	437	419
	R	337	411	371	402	359	435	362	395	364	394
	R	446	438	439	357	442	403	445	390	466	379
	B	341	417	393	410	371	437	342	405	373	440
F	R	396	473	400	466	397	471	405	444	397	461
	B	469	430	503	434	499	401	517	450	483	402
	B	428	480	416	467	437	482	416	457	411	464
	R	441	439	449	405	453	453	434	425	466	392

(continued)

Table 1 (continued)

Sub	Order	LVF									
		GP1		GP2		GP3		GP4		GP5	
		X	V	X	V	X	V	X	V	X	V
G	R	443	417	429	430	405	447	409	386	435	430
	B	507	425	456	430	505	434	444	408	498	419
·	B	431	432	417	433	398	411	382	392	420	388
	R	483	526	496	501	454	514	485	493	549	501
H	R	505	510	460	498	476	486	523	505	487	518
	B	521	485	552	498	523	515	516	478	509	474
	B	453	506	446	524	485	502	486	524	459	523
	R	504	468	509	482	530	457	526	457	515	474
I	R	425	393	439	360	421	370	396	376	434	397
	B	409	444	382	432	377	455	379	427	443	431
	B	478	380	453	390	502	397	435	390	494	364
	R	520	531	509	501	528	504	544	552	507	532
J	R	450	438	418	442	414	437	398	444	427	446
	B	437	430	434	435	415	410	420	414	419	445
	B	467	483	429	490	444	493	409	467	427	480
	R	428	404	427	414	424	413	417	388	426	418
		RVF									
A	B	328	337	335	343	358	326	349	307	341	339
	R	322	315	322	322	290	299	286	328	323	320
	R	322	326	341	324	341	344	323	345	333	329
	B	308	324	293	338	284	317	303	332	309	314
B	B	459	452	425	444	467	437	403	444	442	450
	R	427	386	441	409	408	394	390	359	422	402
	R	444	449	444	416	488	453	452	455	430	455
	B	431	446	432	374	455	413	448	427	467	421
C	B	403	375	384	399	351	383	330	395	430	397
	R	389	344	355	304	375	306	312	282	365	322
	R	352	363	352	366	328	354	313	355	308	363
	B	364	321	387	318	376	319	359	313	378	336
D	B	436	421	419	422	469	407	471	410	422	401
	R	345	357	386	401	372	395	414	412	411	416
	R	400	401	401	388	381	397	376	371	414	368
	B	389	429	374	405	387	423	377	427	380	425
E	B	383	455	348	453	394	472	361	462	378	467
	R	419	353	405	337	406	350	409	368	404	372
	R	365	434	388	415	386	438	442	433	385	430
	B	414	359	386	377	407	385	396	360	426	359

(continued)

Table 1 (continued)

Sub	Order	RVF									
		GP1		GP2		GP3		GP4		GP5	
		X	V	X	V	X	V	X	V	X	V
F	R	409	406	442	403	432	405	423	411	435	413
	B	414	448	416	421	422	431	425	429	407	444
	B	440	421	426	432	437	445	456	423	440	426
	R	406	441	391	425	397	457	390	440	409	429
G	R	420	393	417	395	438	413	451	386	482	438
	B	423	439	449	467	428	449	395	443	432	457
	B	394	433	413	409	368	409	395	424	405	420
	R	470	544	462	491	473	490	523	520	485	512
H	R	508	484	504	450	485	434	525	474	512	474
	B	502	495	482	505	509	548	511	514	542	525
	B	603	439	561	440	571	452	528	464	569	445
	R	506	493	550	504	519	484	514	495	494	518
I	R	481	424	392	407	382	442	364	428	408	403
	B	441	420	452	419	433	420	443	395	455	405
	B	399	457	396	404	394	414	409	429	428	431
	R	490	517	513	515	495	474	513	509	502	492
J	R	437	401	446	417	421	397	413	402	411	393
	B	431	446	402	427	360	435	407	416	386	429
	B	469	440	454	458	476	461	449	461	460	429
	R	404	437	392	423	415	440	390	412	388	431

Table 2. ANOVA: Order x (Session x GP x VF x Stimulus).

Source	df	SS	MS	F	p
Order	1	851186.281	851186.281	8.62	0.02
Subj(O)	8	790394.579	98799.322		
Session	3	30942.773	10314.257	1.14	
O*Se	3	106626.423	35542.141	3.92	0.02
Sub*Se(O)	24	217720.140	9071.672		
GP	4	8310.604	2077.651	2.96	0.05
O*GP	4	1788.749	447.187	0.64	
Sub*GP(O)	32	22438.895	701.215		
VF	1	5115.661	5115.661	3.39	
O*VF	1	98.701	98.701	0.07	
Sub*VF(O)	8	12068.650	1508.581		
Stimulus	1	341.911	341.911	0.11	
O*St	1	1428.451	1428.451	0.45	
Sub*St(O)	8	25143.950	3142.993		
Se*GP	12	4661.995	388.499	0.80	
O*Se*GP	12	1705.569	142.130	0.29	
Sub*Se*GP(O)	96	46622.284	485.648		
Se*VF	3	453.063	151.021	0.28	
O*Se*VF	3	405.143	135.047	0.25	
Sub*Se*VF(O)	24	13004.030	541.834		
Se*St	3	1873.693	624.564	0.53	
O*Se*St	3	614.113	204.704	0.17	

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
Sub*Se*St(O)	24	28350.529	1181.272		
GP*VF	4	1642.620	410.655	1.94	
O*GP*VF	4	174.055	43.513	0.21	
Sub*GP*VF(O)	32	6764.374	211.386		
GP*St	4	1086.794	271.698	0.92	
O*GP*St	4	793.080	198.270	0.67	
Sub*GP*St(O)	32	9484.874	296.402		
VF*St	1	556.111	556.111	0.32	
O*VF*St	1	863.201	863.201	0.49	
Sub*VF*St(O)	8	13998.199	1749.774		
Se*GP*VF	12	3111.880	259.323	0.88	
O*Se*GP*VF	12	2253.125	187.760	0.64	
Sub*Se* GP*VF(O)	96	28296.444	294.754		
Se*GP*St	12	2673.924	222.827	0.79	
O*Se*GP*St	12	3644.480	303.706	1.08	
Sub*Se* GP*St(O)	96	27096.945	282.259		
Se*VF*St	3	1288.793	429.597	0.06	
O*Se*VF*St	3	37282.423	12427.474	1.84	

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
Sub*Se*					
VF*St(O)	24	161844.720	6743.530		
GP*VF*St	4	685.319	171.330	0.57	
O*GP*VF*St	4	1805.754	451.438	1.51	
Sub*GP*					
VF*St(O)	32	9586.975	299.592		
Se*GP*VF*St	12	1490.700	124.225	0.50	
O*Se*GP*VF*S	12	2366.544	197.212	0.80	
Su*Se*GP*					
VF*St(O)	96	23672.004	246.583		
Total	799	2513759.548			

Table 3. ANOVA: Order x (Session x GP x VF).

Source	df	SS	MS	F	p
Order	1	411907.240	411907.240	8.43	0.02
Sub(O)	8	390903.250	48862.906		
Session	3	13118.569	4372.856	0.97	
O*Se	3	58707.940	19569.313	3.89	0.03
Sub*Se(O)	24	120796.390	5033.182		
GP	4	3815.015	953.753	2.93	0.05
O*GP	4	444.485	111.121	0.34	
Sub*GP(O)	32	10419.400	325.606		
VF	1	3340.840	3340.840	3.65	
O*VF	1	1246.090	1246.090	1.36	
Sub*VF(O)	8	7331.170	916.396		
Se*GP	12	1687.905	140.658	0.58	
O*Se*GP	12	962.034	80.169	0.37	
Sub*Se*GP(O)	96	23472.160	244.501		
Se*VF	3	106.900	35.633	0.13	
O*Se*VF	3	267.209	89.070	0.32	
Sub*Se*VF(O)	24	6412.389	267.182		

(continued)

Table 3 (continued)

Source	df	SS	MS	F	p
GP*VF	4	632.985	158.246	1.65	
O*GP*VF	4	136.235	34.058	0.36	
Sub*GP*VF(O)	32	3000.679	93.771		
Se*GP*VF	12	1575.374	131.281	0.88	
O*Se*GP*VF	12	1502.765	125.230	0.84	
S*Se*GP*VF(O)	96	14249.360	148.430		
Total	399	1076036.390	2696.833		

Table 4. ANOVA: Condition x GP x VF, collapsed over Sessions and Stimulus.

Horizontal GPs

Source	df	SS	MS	F	p
Subj	9	245812.602	27312.511		
Cond	1	2470.668	2470.668	1.90	
Subj*Cond	9	11716.602	1301.844		
GP	2	880.212	440.106	3.01	0.08
Subj*GP	18	2635.329	146.407		
Cond*GP	2	259.587	129.793	0.71	
Subj*Cond*GP	18	3296.454	183.136		
VF	1	1303.502	1303.502	4.45	0.07
Subj*VF	9	2634.852	292.761		
Cond*VF	1	111.168	111.168	0.75	
Subj*Cond*VF	9	1334.352	148.261		
GP*VF	2	208.429	104.214	1.86	
Subj*GP*VF	18	1007.029	55.946		
Cond*GP*VF	2	517.387	258.693	2.32	
Su*Con*GP*VF	18	2005.404	111.411		
Total	119	276193.581	2320.954		

(continued)

Table 4 (continued)

Vertical GPs

Source	df	SS	MS	F	p
Subj	9	237239.627	26359.958		
Cond	1	1508.752	1508.752	1.73	
Subj*Cond	9	7865.643	873.960		
GP	2	151.287	75.643	0.47	
Subj*GP	18	2868.254	159.347		
Cond*GP	2	219.829	109.914	0.95	
Subj*Cond*GP	18	2088.212	116.011		
VF	1	1206.502	1206.502	3.86	0.08
Subj*VF	9	2815.060	312.784		
Cond*VF	1	63.802	63.802	0.55	
Subj*Cond*VF	9	1047.927	116.436		
GP*VF	2	248.579	124.289	3.20	0.07
Subj*GP*VF	18	698.795	38.821		
Cond*GP*VF	2	12.304	6.152	0.30	
Su*Con*GP*VF	18	370.904	20.605		
Total	119	258405.481	2171.474		

Table 5. ANOVA: GP x VF, collapsed over Condition, Session and Stimulus.

Horizontal GPs

Source	df	SS	MS	F	p
Subject	9	122906.301	13656.255		
GP	2	440.106	220.053	3.01	0.08
Sub*GP	18	1317.664	73.203		
VF	1	651.751	651.751	4.45	0.07
Sub*VF	9	1317.426	146.380		
GP*VF	2	104.214	52.107	1.86	
Sub*GP*VF	18	503.514	27.973		
Total	59	127240.978	2156.626		

Vertical GPs

Source	df	SS	MS	F	p
Subj	9	118619.813	13179.979		
GP	2	75.643	37.821	0.47	
Subj*GP	18	1434.127	79.673		
VF	1	603.251	603.251	3.86	0.08
Subj*VF	9	1407.530	156.392		
GP*VF	2	124.289	62.144	3.20	0.07
Subj*GP*VF	18	349.397	19.410		
Total	59	122614.053	2078.204		

Table 6. Simple main effects: GP x VF.

Blocked condition: Horizontal GPs

Source	df	SS	MS	F	p
Subj	9	118615.187	13179.465		
GP	2	627.925	313.962	1.75	
Subj*GP	18	3230.325	179.462		
VF	1	1088.004	1088.004	3.50	
Subj*VF	9	2798.787	310.976		
GP*VF	2	47.008	23.504	0.69	
Subj*GP*VF	18	1096.575	60.920		
Total	59	127503.812	2161.081		

Blocked condition: Vertical GPs

Source	df	SS	MS	F	p
Subj	9	107689.370	11965.485		
GP	2	288.958	144.479	0.95	
Subj*GP	18	2728.291	151.571		
VF	1	357.704	357.704	1.11	
Subj*VF	9	2887.504	320.833		
GP*VF	2	87.558	43.779	1.32	
Subj*GP*VF	18	598.358	33.242		
Total	59	114637.745	1943.012		

(continued)

Table 6 (continued)

Random condition: Horizontal GPs

Source	df	SS	MS	F	p
Subj	9	138914.016	15434.890		
GP	2	511.875	255.937	1.71	
Subj*GP	18	2701.458	150.081		
VF	1	326.666	326.666	2.51	
Subj*VF	9	1170.416	130.046		
GP*VF	2	678.808	339.404	3.19	0.07
Subj*GP*VF	18	1915.858	106.436		
Total	59	146219.100	2478.289		

Random condition: Vertical GPs

Source	df	SS	MS	F	p
Subj	9	137415.900	15268.433		
GP	2	82.158	41.079	0.33	
Subj*GP	18	2228.175	123.787		
VF	1	912.600	912.600	8.42	0.02
Subj*VF	9	975.483	108.387		
GP*VF	2	173.325	86.662	3.31	0.06
Subj*GP*VF	18	471.341	26.185		
Total	59	142258.983	2411.169		

Appendix E3

Experiment 3

Table 1. Individual mean median RTs (msec) as a function of GP, VF and Stimulus. VF and conditions are shown separately. W=word; NW= nonword.

Blocked

CVF

GP1		GP2		GP3		GP4		GP5	
W	NW	W	NW	W	NW	W	NW	W	NW
455	535	459	517	500	515	462	524	484	522
530	554	530	600	582	568	589	571	539	569
617	611	599	590	590	578	548	581	570	589
453	508	461	478	460	486	459	469	504	513
558	584	509	525	516	536	501	534	498	517
556	580	497	552	490	563	517	550	528	560
414	498	427	483	414	478	428	466	423	499
556	608	562	593	554	588	532	573	535	615
540	532	528	558	511	519	511	550	495	534
475	529	465	500	466	519	493	506	457	493
461	467	467	494	497	521	462	501	485	522
436	435	485	441	473	436	477	438	460	435

LVF

GP1		GP2		GP3		GP4		GP5	
W	NW	W	NW	W	NW	W	NW	W	NW
519	408	526	436	523	428	514	427	518	417
554	542	572	545	590	568	584	561	562	540
599	509	618	542	623	524	572	509	597	540
526	446	545	429	494	434	484	425	525	445
545	493	564	445	583	458	553	462	465	458
566	485	551	481	558	515	565	479	570	520
510	363	518	416	487	400	466	375	516	393
593	500	593	501	575	526	589	495	561	507
532	449	578	472	568	470	558	452	539	434
490	459	487	449	494	446	484	469	482	450
510	444	493	443	512	480	481	440	553	446
436	426	493	438	464	398	431	447	442	430

(continued)

Table 1 (continued)

RVF

GP1		GP2		GP3		GP4		GP5	
W	NW	W	NW	W	NW	W	NW	W	NW
503	450	503	480	514	461	512	496	527	473
559	580	547	565	555	615	566	584	564	591
613	573	571	594	609	541	552	542	586	544
467	462	482	447	476	473	473	430	500	475
558	533	514	490	518	520	504	495	524	523
562	529	522	514	537	513	527	520	557	542
485	414	450	426	484	404	470	404	467	422
558	567	569	534	566	571	568	537	552	570
501	521	522	510	538	505	531	487	518	487
485	473	481	505	514	491	478	459	463	468
486	473	483	449	516	468	493	457	498	464
407	428	452	473	447	512	429	494	436	466

Random

CVF

522	515	510	520	514	529	530	535	507	521
594	571	593	611	609	612	579	635	567	590
534	561	521	569	532	563	518	549	514	602
475	530	487	524	489	531	476	519	484	542
497	531	495	536	508	540	516	551	512	549
487	509	491	544	471	500	477	511	508	521
497	587	504	563	484	560	504	558	496	579
459	498	475	490	489	490	468	495	464	476
525	540	499	534	510	552	508	533	499	515
536	543	552	531	532	569	537	533	547	541

(continued)

Table 1 (continued)

LVF

GP1		GP2		GP3		GP4		GP5	
W	NW	W	NW	W	NW	W	NW	W	NW
505	503	544	491	534	478	546	482	533	501
616	472	623	471	597	474	582	468	641	440
624	459	600	486	600	476	566	477	570	486
528	457	531	471	516	473	545	459	518	452
567	460	555	478	565	491	561	465	580	474
521	460	518	465	543	455	560	464	527	448
557	468	584	453	562	488	557	457	590	453
525	431	517	431	528	426	510	430	533	421
545	494	540	479	560	483	541	462	556	478
549	497	530	513	528	492	526	487	534	499

RVF

480	530	509	508	509	507	507	519	508	511
568	567	543	528	551	538	567	526	565	527
537	513	540	502	555	511	555	520	542	502
509	500	502	453	515	485	498	485	496	471
538	501	497	510	529	512	525	496	528	496
508	492	491	480	491	508	485	477	528	469
504	504	502	480	512	509	517	491	526	488
490	467	466	450	499	458	492	456	488	461
525	524	491	499	519	508	512	504	513	494
495	522	498	563	538	534	519	532	524	519

Table 2: ANOVA of Condition x (GP x VF x Stimulus).

Source	df	SS	MS	F	p
Condition	1	13338.952	13338.952	0.34	
Sub(C)	20	783300.037	39165.001		
GP	4	3995.697	998.924	2.05	
C*GP	4	877.280	219.320	0.45	
Sub*GP(C)	80	39054.496	488.181		
VF	2	139542.809	69771.404	89.11	0.0001
C*VF	2	4322.551	2161.275	2.76	0.08
Sub*VF(C)	40	31317.936	782.948		
St	1	258853.526	258853.526	67.97	0.0001
C*St	1	1450.719	1450.719	0.38	
Sub*St(C)	20	76169.888	3808.494		
GP*VF	8	1809.747	226.218	1.22	
C*GP*VF	8	1040.775	130.096	0.70	
Sub*GP*VF(C)	160	29652.656	185.329		
GP*St	4	679.474	169.868	0.68	
C*GP*St	4	1649.985	412.496	1.65	
Sub*GP*St(C)	80	19988.264	249.853		

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
VF*St	2	5673.485	2836.742	6.79	0.005
C*VF*St	2	1586.253	793.126	1.90	
Sub*VF*St(C)	40	16705.125	417.628		
GP*VF*St	8	3165.236	395.654	1.90	0.07
C*GP*VF*St	8	1707.006	213.375	1.03	
S*GP*VF*St(C)	160	33252.897	207.830		
Total	659	1465912.765	2224.450		

Table 3. ANOVAs: Condition x GP x VF x Stimulus for the CVF only (upper panel), and LVF and RVF only (lower panel).

CVF

Source	df	SS	MS	F	p
Cond	1	610.310	610.310	0.05	
Subj(Cond)	20	230510.622	11525.531		
GP	4	2426.170	606.542	3.18	0.02
Cond*GP	4	206.497	51.624	0.27	
Su*GP(Con)	80	15253.723	190.671		
Stim	1	125406.149	125406.149	80.13	0.0001
Cond*St	1	103.375	103.375	0.07	
Su*St(Con)	20	31298.994	1564.949		
GP*St	4	2129.139	532.284	2.95	0.025
Con*GP*St	4	724.752	181.188	1.00	
S*GP*St(C)	80	14447.918	180.598		
Total	219	424566.657	1938.660		

LVF and RVF

Source	df	SS	MS	F	p
Cond	1	15371.650	15371.650	0.54	
Sub(Cond)	20	571070.322	28553.516		
GP	4	2714.665	678.666	1.56	
Cond*GP	4	766.323	191.580	0.44	

(continued)

Table 3 (continued)

Source	df	SS	MS	F	p
Subj*GP(Cond)	80	34878.976	435.987		
VF	1	5097.683	5097.683	7.82	0.01
Cond*VF	1	1679.543	1679.543	2.58	
Su*VF(Cond)	20	13037.029	651.851		
Stim	1	138916.909	138916.909	51.08	0.0001
Cond*Stim	1	2898.515	2898.515	1.07	
Su*Sti(Con)	20	54388.947	2719.447		
GP*VF	4	664.609	166.152	0.72	
Cond*GP*VF	4	945.235	236.308	1.02	
Su*GP*VF(Con)	80	18574.452	232.180		
GP*Stim	4	1131.228	282.807	1.10	
Cond*GP*Stim	4	1056.589	264.147	1.02	
Sub*GP*St(C)	80	20654.072	258.175		
VF*Stim	1	203.952	203.952	0.57	
Cond*VF*Stim	1	35.081	35.081	0.10	
Sub*VF*St(C)	20	7187.072	359.353		
GP*VF*Stim	4	584.343	146.085	0.64	
Con*GP*VF*Sti	4	1575.650	393.912	1.74	
S*GP*VF*St(C)	80	18139.172	226.739		
Total	439	909105.997	2070.856		

Table 4. ANOVAs: GP x VF x Stimulus for CVF only.

Horizontal GPs

Source	df	SS	MS	F	p
Subj	21	134263.060	6393.479		
GP	2	2445.526	1222.763	9.56	0.0005
Subj*GP	42	5371.973	127.904		
St	1	67864.007	67864.007	98.12	0.0001
Subj*St	21	14525.159	691.674		
GP*St	2	1376.026	688.013	4.20	0.03
Subj*GP*St	42	6886.806	163.971		
Total	131	232732.560	1776.584		

Vertical GPs

Source	df	SS	MS	F	p
Subj	21	151993.810	7237.800		
GP	2	1169.003	584.501	3.01	0.06
Subj*GP	42	8142.996	193.882		
St	1	87421.280	87421.280	81.20	0.0001
Subj*St	21	22609.803	1076.654		
GP*St	2	62.981	31.490	0.14	
Subj*GP*St	42	9285.185	221.072		
Total	131	280685.060	2142.634		

Table 5. One way ANOVAs for the CVF for words (upper panel) and non-words (lower panel). The ANOVA for words is based on GP4 vs the average of GP2 and GP3 and that for non-words on GP3 vs the average of GP2 and GP4.

Words only

Source	df	SS	MS	F	p
Subj	21	69798.115	3323.719		
GP	1	862.926	862.926	4.43	0.05
Subj*GP	21	3210.115	152.862		
Total	43	83678.272	1946.006		

Non-words only

Source	df	SS	MS	F	p
Subj	21	61625.719	2934.558		
GP	1	2418.371	2418.371	19.22	0.0002
Subj*GP	21	2538.295	120.871		
Total	43	74139.655	1724.178		

Table 6. ANOVAs: GP x VF x Stimulus for LVF and RVF only. The analysis for the horizontal GPs is presented in the top panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	21	353695.144	16842.625		
GP	2	2362.598	1181.299	4.69	0.02
Sub*GP	42	10580.068	251.906		
VF	1	4284.213	4284.213	10.69	0.005
Sub*VF	21	8415.516	400.738		
GP*VF	2	299.749	149.874	0.65	
Sub*GP*VF	42	9707.583	231.132		
St	1	81428.531	81428.531	48.29	0.0001
Sub*St	21	35410.614	1686.219		
GP*St	2	780.295	390.147	2.16	
Sub*GP*St	42	7603.121	181.026		
VF*St	1	304.440	304.440	0.69	
Sub*VF*St	21	9440.788	449.561		
GP*VF*St	2	577.022	288.511	1.60	
S*GP*VF*St	42	7590.560	180.727		
Total	263	532480.249	2024.639		

(continued)

Table 6 (continued)

Vertical GPs

Source	df	SS	MS	F	p
Sub	21	359047.375	17097.494		
GP	2	782.422	391.211	0.77	
Sub*GP	42	21319.244	507.601		
VF	1	1685.185	1685.185	2.29	
Sub*VF	21	15469.814	736.657		
GP*VF	2	128.160	64.080	0.31	
Sub*GP*VF	42	8558.589	203.775		
St	1	77936.727	77936.727	43.14	0.0001
Sub*St	21	37940.606	1806.695		
GP*St	2	449.392	224.696	0.80	
Sub*GP*St	42	11767.024	280.167		
VF*St	1	200.378	200.378	0.66	
Sub*VF*St	21	6406.621	305.077		
GP*VF*St	2	281.660	140.830	0.53	
Su*GP*VF*St	42	11227.839	267.329		
Total	263	553201.041	2103.426		

Table 7. ANOVAs: GP x VF for LVF and RVF only. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	21	176847.572	8421.312		
GP	2	1181.299	590.649	4.69	0.02
Sub*GP	42	5290.034	125.953		
VF	1	2142.106	2142.106	10.69	0.005
Sub*VF	21	4207.758	200.369		
GP*VF	2	149.874	74.937	0.65	
Sub*GP*VF	42	4853.791	115.566		
Total	131	194672.437	1486.049		

Vertical GPs

Source	df	SS	MS	F	p
Sub	21	179523.687	8548.747		
GP	2	391.211	195.605	0.77	
Sub*GP	42	10659.622	253.800		
VF	1	842.592	842.592	2.29	
Sub*VF	21	7734.907	368.328		
GP*VF	2	64.080	32.040	0.31	
Sub*GP*VF	42	4279.2945	101.887		
Total	131	203495.395	1553.400		

Table 8. ANOVAs: Simple main effects for GP x VF. Separate ANOVAs are shown for Blocked and Random conditions, and also for horizontal and vertical GPs, as indicated.

Blocked: Horizontal GPs

Source	df	SS	MS	F	p
Subj	11	131805.604	11982.327		
GP	2	1387.763	693.881	3.84	0.05
Sub*GP	22	3977.865	180.811		
VF	1	703.120	703.125	2.85	
Sub*VF	11	2717.561	247.051		
GP*VF	2	72.220	36.111	0.25	
Sub*GP*VF	22	3376.022	153.455		
Total	71	144040.162	2028.734		

Blocked: Vertical GPs

Source	df	SS	MS	F	p
Sub	11	134474.333	12224.939		
GP	2	267.859	133.929	0.30	
Sub*GP	22	9857.182	448.053		
VF	1	8.000	8.000	0.02	
Sub*VF	11	4165.875	378.715		
GP*VF	2	290.942	145.471	1.48	
Sub*GP*VF	22	2162.682	98.303		
Total	71	151226.875	2129.955		

(continued)

Table 8 (continued)

Randomized.: Horizontal GPs

Source	df	SS	MS	F	p
Sub	9	40168.626	4463.180		
GP	2	163.181	81.590	1.56	
Sub*GP	18	942.527	52.362		
VF	1	1568.259	1568.259	10.37	0.01
Sub*VF	9	1360.917	151.213		
GP*VF	2	100.143	50.071	0.62	
Sub*GP*VF	18	1455.272	80.848		
Total	59	45758.928	775.575		

Randomized: Vertical GPs

Source	df	SS	MS	F	p
Sub	9	40956.254	4550.694		
GP	2	130.158	65.079	1.47	
Sub*GP	18	795.633	44.201		
VF	1	1596 4	1596.504	5.21	0.05
Sub*VF	9	2807.120	311.902		
GP*VF	2	179.158	89.579	0.94	
Sub*GP*VF	18	1710.591	95.032		
Total	59	48175.420	816.532		

Table 9. ANOVAs: GP x VF x Stimulus for the CVF *vs* the average of LVF and RVF collapsed over Condition. The analysis for the horizontal GPs appears in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	21	400852.601	19088.219		
GP	2	4046.181	2023.090	8.44	0.001
Sub*GP	42	10066.484	239.678		
VF	1	77459.666	77459.666	116.50	0.0001
Sub*VF	21	13961.576	664.836		
GP*VF	2	789.585	394.792	4.00	0.05
Sub*GP*VF	42	4149.525	98.798		
St	1	142471.598	142471.598	84.43	0.0001
Sub*St	21	35436.810	1687.467		
GP*St	2	201.532	100.766	0.45	
Sub*GP*St	42	9409.994	224.047		
VF*St	1	2299.432	2299.432	6.41	0.02
Sub*VF*St	21	7537.144	358.911		
GP*VF*St	2	2153.366	1076.683	9.34	0.0001
S*GP*VF*St	42	4841.161	115.265		
Total	263	802052.601	3049.629		

(continued)

Table 9 (continued)

Vertical GPs

Source	df	SS	MS	F	p
Subj	21	428034.776	20382.608		
GP	2	1394.865	697.432	1.71	
Subj*GP	42	17142.217	408.148		
VF	1	75309.001	75309.001	113.06	0.0001
Subj*VF	21	13988.554	666.121		
GP*VF	2	685.421	342.710	1.82	
Subj*GP*VF	42	7927.940	188.760		
St	1	162081.944	162081.944	75.53	0.0001
Subj*St	21	45064.277	2145.917		
GP*St	2	350.171	175.085	0.70	
Subj*GP*St	42	10557.106	251.359		
VF*St	1	6437.580	6437.580	13.03	0.002
Subj*VF*St	21	10375.863	494.088		
GP*VF*St	2	33.398	16.699	0.07	
S*GP*VF*St	42	9667.823	230.186		
Total	263	865236.853	3289.873		

Table 10. ANOVAs: GP x VF for the CVF *vs* the average of the LVF and RVF collapsed over Stimulus. The analysis for the horizontal GPs appears in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	21	200426.300	9544.109		
GP	2	2023.090	1011.545	8.44	0.001
Sub*GP	42	5033.242	119.839		
VF	1	38729.833	38729.833	116.51	0.0001
Sub*VF	21	6980.788	332.418		
GP*VF	2	394.792	197.396	4.00	0.03
Sub*GP*VF	42	2074.762	49.399		
Total	131	293089.019	2237.320		

Vertical GPs

Source	df	SS	MS	F	p
Sub	21	214017.388	10191.304		
GP	2	697.432	348.716	1.71	
Sub*GP	42	8571.108	204.074		
VF	1	37654.500	37654.500	113.06	0.0001
Sub*VF	21	6994.277	333.060		
GP*VF	2	342.710	171.355	1.82	
Sub*GP*VF	42	3963.970	94.380		
Total	131	308881.926	2357.877		

Appendix E4

Experiment 4

Table 1. Individual mean median RTs (msec) as a function of Condition x GP x VF x Stimulus. Blocked data for each VF are given in the upper panel, Randomized data in the lower panel. H=Horizontal, V=Vertical.

Blocked

CVF

GP1		GP2		GP3		GP4		GP5	
H	V	H	V	H	V	H	V	H	V
445	451	429	463	426	441	456	458	451	419
350	345	350	335	366	336	349	354	351	356
425	377	411	407	395	390	413	378	408	381
390	384	394	370	373	381	430	395	393	355
361	364	359	360	376	354	347	351	371	347
345	326	329	335	338	333	331	344	334	341
403	359	401	368	409	361	381	359	380	351
370	314	352	334	357	320	376	334	353	323
362	360	376	374	372	361	387	392	392	360
337	361	376	367	370	395	375	369	369	397

LVF

GP1		GP2		GP3		GP4		GP5	
H	V	H	V	H	V	H	V	H	V
471	426	434	407	462	448	511	456	474	413
359	356	335	343	356	346	351	349	343	351
374	380	394	383	386	380	377	376	379	385
399	395	404	363	395	350	411	398	398	357
382	360	365	363	360	360	358	359	354	377
349	335	336	344	348	333	348	327	349	328
383	360	382	381	379	403	379	365	369	375
364	329	356	352	351	328	352	333	357	320
379	380	364	385	358	364	392	377	398	381
379	363	368	370	390	370	368	376	394	395

(continued)

Table 1 (continued)

RVF

GP1		GP2		GP3		GP4		GP5	
H	V	H	V	H	V	H	V	H	V
463	452	461	441	470	425	461	449	465	400
336	367	358	363	372	337	367	360	346	340
376	365	399	378	360	371	375	373	371	403
396	380	391	378	396	363	408	385	421	377
365	359	355	352	345	367	346	354	363	353
355	356	340	352	346	339	361	329	343	325
350	389	368	395	369	404	355	380	357	387
352	364	365	370	338	339	371	339	371	347
341	360	363	369	355	363	382	377	358	357
387	363	370	370	366	369	373	367	373	372

Random

CVF

GP1		GP2		GP3		GP4		GP5	
399	388	396	399	380	395	381	390	385	397
367	344	348	340	349	327	346	344	336	332
369	358	364	363	368	376	353	362	374	359
360	367	344	356	366	367	355	346	344	350
327	315	312	312	316	325	319	302	311	311
368	397	365	379	387	385	387	388	368	387
387	366	401	362	424	387	377	379	404	376
423	400	398	408	415	381	394	387	416	396
361	345	339	347	324	342	316	361	327	373
384	353	377	376	374	351	354	363	361	362

LVF

GP1		GP2		GP3		GP4		GP5	
408	377	391	376	410	374	403	377	397	377
333	309	339	318	337	335	333	337	336	316
363	340	372	342	362	337	370	316	366	344
373	327	366	328	394	316	361	356	373	329
326	313	329	299	332	307	341	309	335	301
384	358	393	358	405	361	393	342	389	352
411	359	384	346	409	379	392	384	401	357
435	343	445	370	409	346	436	364	460	359
351	289	355	296	340	278	380	281	359	289
364	354	392	372	396	378	379	347	346	354

Table 1 (continued)

RVF

GP1		GP2		GP3		GP4		GP5	
H	V	H	V	H	V	H	V	H	V
362	396	362	381	376	388	375	381	388	386
327	343	325	359	317	323	311	326	328	333
368	365	360	359	368	363	373	356	352	355
388	343	348	342	353	341	363	368	368	349
296	322	328	317	340	322	337	314	308	317
367	381	374	391	371	371	373	373	388	366
398	395	416	367	382	358	388	396	379	362
399	373	369	375	392	368	370	379	359	361
366	325	357	323	352	324	364	328	348	339
342	355	342	336	347	360	355	368	354	351

Table 2. ANOVA: Condition x GP x VF x Stimulus.

Source	df	SS	MS	F	p
Condition (C)	1	28794.153	28794.153	1.24	
Subj(C)	18	417227.004	23179.278		
GP	4	767.314	191.828	0.89	
C*GP	4	762.019	190.504	0.89	
Sub*GP(C)	72	15452.633	214.619		
VF	2	24395.343	12197.671	29.43	0.0001
C*VF	2	6040.929	3020.465	7.29	0.005
Sub*VF(C)	36	14921.743	414.492		
Stimulus	1	7480.070	7480.070	6.09	0.03
C*St	1	5307.400	5307.400	4.32	0.05
Sub*St(C)	18	22093.004	1227.389		
GP*VF	8	1089.573	136.196	1.16	
C*GP*VF	8	893.678	111.709	0.96	
Sub*GP*VF(C)	144	16841.731	116.956		
GP*St	4	436.669	109.167	0.82	
C*GP*St	4	54.014	13.503	0.10	
Sub*GP*St(C)	72	9639.549	133.882		
VF*St	2	3086.963	1543.481	3.62	0.05

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
C*VF*St	2	56.303	28.151	0.07	
Sub*VF*St(C)	36	15354.583	426.516		
GP*VF*St	8	549.253	68.656	0.52	
C*GP*VF*St	8	1411.638	176.454	1.33	
S*GP*VF*St(C)	144	19077.925	132.485		
Total	599	611733.499	1021.257		

Table 3. Group mean median RTs (msec) as a function of
Condition (Blocked vs Random), GP, VF (Left, Right, Centre)
and Stimulus (Horizontal vs Vertical).

GP	VF	Stim	Blocked Mean	Blocked s.d.	Random Mean	Random s.d.
1	L	H	384.20	33.54	375.05	35.00
		V	379.00	35.81	374.65	25.71
	R	H	364.40	37.30	363.50	26.45
		V	375.70	28.82	360.00	26.72
	C	H	372.45	37.18	361.50	32.21
		V	368.70	28.41	337.30	27.10
2	L	H	374.00	30.59	376.85	32.70
		V	377.95	30.97	364.70	29.30
	R	H	371.55	39.14	364.40	28.22
		V	377.05	25.92	355.30	24.75
	C	H	377.25	34.05	358.25	26.07
		V	369.35	20.43	340.80	29.40
3	L	H	378.95	33.95	379.70	32.95
		V	378.45	25.42	370.45	34.53
	R	H	367.60	35.81	363.85	25.71
		V	367.95	28.50	352.05	23.10
	C	H	371.90	38.35	360.05	22.39
		V	368.50	35.70	341.30	33.62
4	L	H	385.10	48.57	379.05	30.07
		V	384.80	38.98	358.50	26.88
	R	H	373.65	35.81	362.45	26.92
		V	371.70	32.67	359.15	27.28
	C	H	380.00	33.14	361.10	22.15
		V	371.80	36.59	341.60	31.78
5	L	H	381.60	38.59	376.40	37.85
		V	380.40	33.25	362.95	33.52
	R	H	363.25	28.23	364.65	27.70
		V	366.40	26.03	352.25	19.25
	C	H	377.00	37.81	357.50	25.63
		V	368.45	29.13	338.15	28.07

Table 4. ANOVAs: Condition x GP x VF for the CVF only.
Separate ANOVAs are shown for horizontal GPs (upper panel)
and vertical GPs (lower panel).

Horizontal GPs

Source	df	SS	MS	F	p
Cond	1	7672.704	7672.704	3.53	0.08
Subj(Cond)	18	39111.291	2172.849		
GP	2	106.706	53.353	0.71	
Cond*GP	2	73.189	36.594	0.49	
Subj*GP(Cond)	36	2689.270	74.701		
Total	59	49653.162	841.579		

Vertical GPs

Source	df	SS	MS	F	p
Cond	1	7172.266	7172.266	3.15	
Subj(Cond)	18	40935.216	2274.178		
GP	2	2.077	1.03	0.01	
Cond*GP	2	75.814	37.907	0.54	
Subj*GP(Cond)	36	2504.733	69.575		
Total	59	50690.108	859.154		

Table 5. ANOVAs: Condition x GP x VF for the LVF and RVF
only. Separate ANOVAs are shown for horizontal GPs (upper
panel) and vertical GPs (lower panel).

Horizontal GPs

Source	df	SS	MS	F	p
Cond	1	3116.102	3116.102	0.62	
Subj(Cond)	18	90631.702	5035.094		
GP	2	84.116	42.058	0.36	
Cond*GP	2	268.466	134.233	1.16	
Subj*GP(Cond)	36	4165.291	115.702		
VF	1	3090.675	3090.675	25.91	0.0001
Cond*VF	1	103.602	103.602	0.87	
Subj*VF(Cond)	18	2146.827	119.268		
GP*VF	2	298.387	149.193	2.25	
Cond*GP*VF	2	252.629	126.314	1.91	
S*GP*VF(Con)	36	2382.566	66.182		
Total	119	106540.366	895.297		

(continued)

Table 5 continued)

Vertical GPs

Source	df	SS	MS	F	p
Cond	1	1778.700	1778.700	0.38	
Subj(Cond)	18	84164.079	4675.782		
GP	2	259.879	129.939	1.42	
Cond*GP	2	23.037	11.518	0.13	
Subj*GP(Cond)	36	3305.645	91.823		
VF	1	5346.675	5346.675	25.58	0.0001
Cond*VF	1	6.533	6.533	0.03	
Subj*VF(Cond)	18	3761.687	208.982		
GP*VF	2	16.287	8.143	0.11	
Cond*GP*VF	2	156.829	78.414	1.02	
Su*GP*VF(Con)	36	2769.112	76.919		
Total	119	101588.466	853.684		

Table 6. ANOVAs: GP x VF for the CVF only. Separate ANOVAs are shown for horizontal GPs (upper panel) and vertical GPs (lower panel).

Horizontal GPs

Source	df	SS	MS	F	p
Subj	19	46783.995	2462.315		
GP	2	106.706	53.353	0.73	
Subj*GP	38	2762.460	72.696		
Total	59	49653.162	841.579		

Vertical GPs

Source	df	SS	MS	F	p
Subj	19	48107.483	2531.972		
GP	2	2.077	1.038	0.02	
Subj*GP	38	2580.547	67.909		
Total	59	50690.108	859.154		

Table 7. ANOVAs: GP x VF for the LVF and RVF only. Separate
ANOVAs are shown for horizontal GPs (upper panel) and
vertical GPs (lower panel).

Horizontal GPs

Source	df	SS	MS	F	p
Sub	19	93747.804	4934.094		
GP	2	84.116	42.058	0.36	
Sub*GP	38	4433.758	116.677		
VF	1	3090.675	3090.675	25.09	0.0001
Sub*VF	19	2250.429	118.443		
GP*VF	2	298.387	149.193	2.15	
Sub*GP*VF	38	2635.195	69.347		
Total	119	106540.366	895.297		

Vertical GPs

Source	df	SS	MS	F	p
Sub	19	85942.779	4523.304		
GP	2	259.879	129.939	1.48	
Sub*GP	38	3328.683	87.596		
VF	1	5346.675	5346.675	26.96	0.0001
Sub*VF	19	3768.220	198.327		
GP*VF	2	16.287	8.143	0.11	
Sub*GP*VF	38	2925.941	76.998		
Total	119	101588.466	853.684		

Appendix E5

Experiment 5

Table 1. Individual mean median RTs (msec) as a function of Condition x GP x VF x Stimulus. Erect (E) and Inverted (I) stimuli are shown separately. Eye turning condition data are given in the first six panels, Head turning data in the last six panels.

Eye turning

CVF   Erect

GP1	GP2	GP3	GP4	GP5
699	694	740	703	708
615	604	625	614	615
788	744	755	718	714
694	699	692	699	662
857	819	952	827	909
594	637	613	599	574
536	598	571	594	606
784	644	780	667	733
818	812	860	813	831
683	630	609	646	637

Inverted

GP1	GP2	GP3	GP4	GP5
882	840	815	924	834
757	675	754	656	742
732	1179	1055	1057	1115
1032	922	1062	975	951
1012	988	1052	940	1029
818	798	729	746	790
825	742	874	875	739
796	753	813	731	700
1233	1151	1223	1190	1140
841	763	805	762	751

(continued)

Table 1 (continued)

LVF   Erect

GP1	GP2	GP3	GP4	GP5
719	742	745	716	719
646	710	660	588	619
743	812	728	694	710
721	694	721	754	695
963	936	899	827	842
706	641	649	608	602
620	563	573	585	574
781	678	748	710	789
834	772	822	858	803
695	706	671	707	685

Inverted

859	872	910	913	877
760	715	711	694	788
1201	980	1077	1103	1010
1020	972	931	887	900
1080	1021	1271	1076	1134
847	895	822	923	829
813	749	796	766	766
785	752	810	835	729
1107	1203	1097	1227	1089
799	842	860	824	771

RVF   Erect

676	722	725	748	742
612	614	755	667	639
688	704	716	789	717
725	656	703	657	750
941	896	875	970	929
656	619	642	701	649
578	568	591	606	615
820	686	746	839	742
868	847	912	834	845
686	679	651	645	664

(continued)

Table 1 (continued)

| | | Inverted | | |
GP1	GP2	GP3	GP4	GP5
892	945	924	923	869
772	714	683	706	768
1155	1059	1018	1126	1133
935	977	983	943	957
1137	1066	1158	1030	1005
895	843	861	863	840
763	809	802	808	819
730	678	896	874	766
1203	1223	1195	1125	1131
868	893	788	868	825

Head turning

CVF

| | | Erect | | |
GP1	GP2	GP3	GP4	GP5
554	651	608	628	630
841	811	811	842	828
748	823	725	766	739
945	911	913	844	788
652	693	659	669	655
602	534	556	610	582
627	635	673	637	647
813	867	808	818	903
703	637	737	732	677
589	567	586	564	577

		Inverted		
618	654	635	693	682
1046	984	1069	990	1007
953	1001	928	981	928
1209	1224	1128	1123	1151
839	804	767	826	781
909	845	766	851	754
761	705	721	735	746
830	926	1175	1046	891
853	822	790	828	787
784	761	714	749	734

Table 1 (continued)

LVF   Erect

GP1	GP2	GP3	GP4	GP5
628	669	657	598	647
864	816	934	820	876
747	715	755	845	737
966	795	1011	998	989
698	669	683	704	698
533	552	547	553	563
703	694	704	723	678
1050	900	830	852	844
675	755	633	693	696
574	590	611	672	662

Inverted

GP1	GP2	GP3	GP4	GP5
674	695	664	758	680
1090	1008	1068	1059	1072
1001	1086	911	1119	948
1235	1225	1224	1202	1111
828	869	830	838	841
876	888	821	919	1008
827	771	790	783	769
1147	1081	1046	946	987
848	877	890	789	829
816	769	761	782	754

RVF   Erect

GP1	GP2	GP3	GP4	GP5
586	634	608	672	616
922	857	843	823	961
767	749	767	738	803
844	913	885	885	863
707	717	712	664	690
582	543	566	567	518
721	754	727	734	701
1070	823	890	845	880
750	720	715	682	674
593	638	591	666	627

(continued)

Table 1 (continued)

Inverted

GP1	GP2	GP3	GP4	GP5
724	693	805	656	711
1054	986	1021	1020	1016
964	1017	1008	822	1017
1254	1241	1278	1247	1231
828	867	853	857	872
874	846	810	881	831
813	773	838	789	847
980	1120	968	980	1164
877	849	875	807	843
782	735	891	762	872

Table 2: ANOVA: Condition x (GP x VF x Stimulus)

Source	df	SS	MS	F	p
C	1	11.620	11.620	0.00	
Sub(C)	18	8351080.467	463948.914		
GP	4	29475.969	7368.992	3.38	0.02
C*GP	4	9911.960	2477.990	1.14	
Sub*GP(C)	72	157148.070	2182.612		
VF	2	120041.000	60020.500	23.46	0.0001
C*VF	2	9066.075	4533.037	1.77	
Sub*VF(C)	36	92109.689	2558.602		
St	1	5159589.933	5159589.933	84.75	0.0001
C*St	1	18888.870	18888.870	0.31	
Sub*St(C)	18	1095834.120	60879.673		
GP*VF	8	11603.565	1450.445	0.67	
C*GP*VF	8	22959.849	2869.981	1.32	
Sub*GP*VF(C)	144	312175.234	2167.883		
GP*St	4	3875.664	968.916	0.48	
C*GP*St	4	2597.085	649.271	0.32	
Sub*GP*St(C)	72	144290.283	2004.031		
VF*St	2	2931.302	1465.651	0.65	
C*VF*St	2	3184.360	1592.180	0.70	
Sub*VF*St(C)	36	81468.736	2263.020		

(continued)

Table 2 (continued)

Source	df	SS	MS	F	p
GP*VF*St	8	12799.205	1599.900	0.71	
C*GP*VF*St	8	20516.239	2564.529	1.01	
Sub*GP*					
VF*St(C)	144	324845.571	2255.872		
Total	599	15986404.879	26688.488		

Table 3. ANOVAs: GP x VF for the CVF only, collapsed over Condition and Stimulus. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	19	886472.583	46656.451		
GP	2	2571.308	1285.654	1.10	
Sub*GP	38	44411.691	1168.728		
Total	59	933455.583	15821.281		

Vertical GPs

Source	df	SS	MS	F	p
Sub	19	883928.837	46522.570		
GP	2	6614.102	3307.051	3.10	0.06
Sub*GP	38	40486.981	1065.446		
Total	59	931029.920	15780.168		

Table 4. ANOVAs: GP x VF for the LVF and RVF only, collapsed over Condition and Stimulus. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	19	1643243.109	86486.479		
GP	2	1963.463	981.731	0.77	
Sub*GP	38	48756.619	1283.068		
VF	1	149.075	149.075	0.24	
Sub*VF	19	11608.747	610.986		
GP*VF	2	974.351	487.175	0.39	
Sub*GP*VF	38	47539.357	1251.035		
Total	119	1754234.724	14741.468		

Vertical GPs

Source	df	SS	MS	F	p
Sub	19	1766327.651	92964.613		
GP	2	5341.782	2670.891	2.52	0.09
Sub*GP	38	40306.134	1060.687		
VF	1	2233.875	2233.875	2.71	
Sub*VF	19	15671.572	824.819		
GP*VF	2	3219.713	1609.856	1.88	
Sub*GP*VF	38	32475.119	854.608		
Total	119	1865575.849	15677.107		

Table 5. ANOVA: GP x VF for the LVF, RVF, and CVF. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Sub	19	2495654.239	131350.223		
GP	2	4156.731	2078.365	1.43	
Sub*GP	38	55181.963	1452.156		
VF	2	29865.202	14932.601	12.42	0.0001
Sub*VF	38	45670.200	1201.847		
GP*VF	4	1352.391	338.097	0.30	
Sub*GP*VF	76	85525.705	1125.338		
Total	179	2717406.434	15181.041		

Vertical GPs.

Source	df	SS	MS	F	p
Sub	19	2620706.214	137931.906		
GP	2	10736.658	5368.329	6.45	0.005
Sub*GP	38	31644.369	832.746		
VF	2	38278.889	19139.444	16.08	0.0001
Sub*VF	38	45221.846	1190.048		
GP*VF	4	4438.939	1109.734	1.03	
Sub*GP*VF	76	81623.865	1073.998		
Total	179	2832650.784	15824.864		

Table 6. ANOVA: GP x VF for the CVF vs the average of LVF and RVF combined. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Subj	19	2243397.397	118073.547		
GP	2	4359.346	2179.673	1.54	
Subj*GP	38	53733.653	1414.043		
VF	1	29716.126	29716.126	16.58	0.001
Subj*VF	19	34061.453	1792.708		
GP*VF	2	378.040	189.020	0.19	
Sub*GP*VF	38	37986.348	999.640		
Total	119	2657134.903	22328.864		

Vertical GPs

Source	df	SS	MS	F	p
Subj	19	2326573.276	122451.225		
GP	2	11160.764	5580.382	6.69	0.005
Subj*GP	38	31704.651	834.332		
VF	1	36045.014	36045.014	23.18	0.0001
Subj*VF	19	29550.274	1555.277		
GP*VF	2	1219.226	609.613	0.47	
Sub*GP*VF	38	49148.746	1293.388		
Total	119	2779050.503	23353.365		

Table 7. ANOVA: Simple main effects for GP x VF for the
Horizontal GPs only. The ANOVA for Eye turning is shown in
the upper panel, that for Head turning in the lower panel.

Eye turning

Source	df	SS	MS	F	p
Sub	9	651893.81	72432.64		
GP	2	1080.90	540.45	0.25	
Sub*GP	18	39685.18	2204.73		
VF	1	2148.01	2148.01	1.82	
Sub*VF	9	10602.40	1178.04		
GP*VF	2	3755.83	1877.91	0.97	
Sub*GP*VF	18	35019.74	1945.54		
Total	59	744185.90	12613.32		

Head turning

Source	df	SS	MS	F	p
Sub	9	980076.08	108897.34		
GP	2	665.42	332.71	0.23	
Sub*GP	18	26390.49	1466.13		
VF	1	1738.81	1738.81	1.08	
Sub*VF	9	14456.43	1606.27		
GP*VF	2	9558.55	4779.27	4.37	0.03
Sub*GP*VF	18	19697.69	1094.31		
Total	59	1052583.50	17840.39		

Table 8. One-way ANOVAs: Data are for the Head turning, horizontal GP conditions only. The ANOVA for the LVF appears in the upper panel, that for the RVF in the lower panel. (The CVF is not included in this analysis.)

LVF

Source	df	SS	MS	F	p
Sub	9	461162.67	51240.29		
GP	2	3420.51	1710.25	0.83	
Sub*GP	18	37200.15	2066.67		
Total	29	501783.34	17302.87		

RVF

Source	df	SS	MS	F	p
Sub	9	533369.84	59263.31		
GP	2	6803.46	3401.73	6.89	0.01
Sub*GP	18	8888.03	493.77		
Total	29	549061.34	18933.14		

Appendix Diff

The ANOVAs in this appendix relate to the the analysis incorporating task difficulty (Experiment) as a factor.

Table 1. ANOVA: Experiment x GP x VF for Experiment 1 *vs* Experiment 2 with the data from Experiment 2 collapsed over conditions. Data are for LVF and RVF only. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs

Source	df	SS	MS	F	p
Expt	1	89.700	89.700	0.01	
Subj(Expt)	18	304286.951	16904.830		
GP	2	405.026	202.513	3.03	0.06
Expt*GP	2	179.488	89.744	1.34	
Subj*GP(Expt)	36	2404.339	66.787		
VF	1	1220.813	1220.813	6.41	0.02
Expt*VF	1	1.354	1.354	0.01	
Subj*VF(Expt)	18	3428.426	190.468		
GP*VF	2	289.013	144.506	5.98	0.01
Expt*GP*VF	2	120.509	60.254	2.50	
Su*GP*VF(Exp)	36	869.289	24.146		
Total	119	313294.911	2632.730		

(continued)

Table 1 (continued)

Vertical GPs

Source	df	SS	MS	F	p
Expt	1	105.938	105.938	0.01	
Subj(Expt)	18	309800.017	17211.112		
GP	2	387.457	193.728	2.83	
Expt*GP	2	55.344	27.672	0.40	
Subj*GP(Expt)	36	2461.635	68.378		
VF	1	1164.075	1164.075	7.02	0.02
Expt*VF	1	0.379	0.379	0.00	
Subj*VF(Expt)	18	2983.534	165.751		
GP*VF	2	52.688	26.344	0.85	
Expt*GP*VF	2	84.959	42.479	1.37	
Su*GP*VF(Exp)	36	1116.706	31.019		
Total	119	318212.736	2674.056		

Table 2. ANOVA: Experiment x GP x VF for the data from Experiments 1, 2, 3, and 4. Data are for LVF and RVF only. The ANOVA for the horizontal GPs is shown in the upper panel, that for the vertical GPs in the lower panel.

Horizontal GPs.

Source	df	SS	MS	F	p
Expt	3	14837753.961	4945917.987	174.19	0.0001
Subj(Expt)	78	2214735.106	28394.039		
GP	2	1675.943	837.971	2.13	
Expt*GP	6	1907.079	317.846	0.81	
Su*GP(Exp)	156	61495.015	394.198		
VF	1	3318.915	3318.915	12.54	0.001
Expt*VF	3	2308.010	769.336	2.91	0.05
Su*VF(Exp)	78	20636.909	264.575		
GP*VF	2	85.558	42.779	0.12	
Expt*GP*VF	6	1910.132	318.355	0.90	
S*GP*VF(E)	156	55377.281	354.982		
Total	491	17201314.683	35033.227		

(continued)

Table 2 (continued)

Vertical GPs

Source	df	SS	MS	F	p
Expt	3	15059247.396	5019749.132	166.87	0.0001
Subj(Expt)	78	2346443.161	30082.604		
GP	2	1805.458	902.729	2.47	
Expt*GP	6	4491.486	748.581	2.05	0.07
Su*GP(Exp)	156	57045.207	365.674		
VF	1	1901.896	1901.896	5.29	0.03
Expt*VF	3	7445.568	2481.856	6.90	0.001
Su*VF(Exp)	78	28066.351	359.825		
GP*VF	2	720.014	360.007	1.36	
Expt*GP*VF	6	2708.348	451.391	1.71	
S*GP*VF(E)	156	41229.284	264.290		
Total	491	17551078.578	35745.577		

Appendix Meta

The ANOVAs in this appendix relate to the meta analysis involving the data from the first four experiments.

Table 1. ANOVA: GP x VF for the data from Experiment 1 and the LVF and RVF data from the randomized conditions of Experiments 2 and 3. (Horizontal GPs only.)

Source	df	SS	MS	F	p
Sub	31	888489.446	28660.949		
GP	2	1265.392	632.696	4.59	0.02
Sub*GP	62	8544.649	137.816		
VF	1	1575.520	1575.520	8.11	0.01
Sub*VF	31	6023.666	194.311		
GP*VF	2	694.063	347.031	3.57	0.05
Sub*GP*VF	62	6019.936	97.095		
Total	191	912612.675	4778.076		

Table 2 ANOVA: GP x VF for the LVF and RVF data from the blocked conditions of Experiments 2 and 3. (Horizontal GPs only.)

Source	df	SS	MS	F	p
Sub	21	606339.804	28873.324		
GP	2	1966.546	983.273	5.69	0.01
Sub*GP	42	7257.328	172.793		
VF	1	1749.092	1749.092	6.61	0.02
Sub*VF	21	5558.386	264.685		
GP*VF	2	8.836	4.418	0.04	
Sub*GP*VF	42	4582.997	109.118		
Total	131	627462.99	4789.793		

Table 3. ANOVA: Condition x GP for Experiments 1, 2 & 3, horizontal GPs only. The ANOVA for the LVF is shown in the upper panel, that for the RVF in the lower panel.

LVF

Source	df	SS	MS	F	p
Cond	1	7702.427	7702.427	0.51	
Sub(Cond)	50	749902.928	14998.058		
GP	2	1737.814	868.907	7.56	0.001
Cond*GP	2	128.253	64.126	0.56	
Sub*GP(Cond)	100	11491.131	114.911		
Total	155	770935.355	4973.776		

RVF

Source	df	SS	MS	F	p
Cond	1	7422.478	7422.478	0.52	
Sub(Cond)	50	717342.349	14346.844		
GP	2	572.059	286.029	3.04	0.05
Cond*GP	2	940.673	470.336	4.99	0.01
Sub*GP(Cond)	100	9417.797	94.177		
Total	155	735621.828	4745.947		

Table 4. ANOVA: GP x VF for the LVF and RVF data from the randomized conditions of Experiments 1, 2 and 3. (Vertical GPs only.)

Source	df	SS	MS	F	p
Sub	31	887249.238	28620.943		
GP	2	33.774	16.887	0.08	
Sub*GP	62	13796.267	222.520		
VF	1	1015.220	1015.220	4.38	0.05
Sub*VF	31	7183.946	231.740		
GP*VF	2	302.961	151.480	2.63	0.08
Sub*GP*VF	62	3575.996	57.677		
Total	191	913157.404	4780.928		

Table 5. ANOVA: GP x VF for the LVF and RVF data from the blocked conditions of Experiments 2 and 3. (Vertical GPs only.)

Source	df	SS	MS	F	p
Sub	21	578443.013	27544.905		
GP	2	21.285	10.642	0.03	
Sub*GP	42	13121.006	312.404		
VF	1	220.229	220.229	0.64	
Sub*VF	21	7198.854	342.802		
GP*VF	2	347.546	173.773	2.61	0.09
Sub*GP*VF	42	2791.995	66.476		
Total	131	602143.929	4596.518		

Table 6. ANOVA: GP x VF for the LVF and RVF data from Experiments 1, 2 and 3, combined over blocked and randomized conditions for the vertical GPs only.

Source	df	SS	MS	F	p
Sub	53	1482232.589	27966.652		
GP	2	2.395	1.197	0.00	
Sub*GP	106	26969.938	254.433		
VF	1	1156.000	1156.000	4.24	0.05
Sub*VF	53	14462.250	272.872		
GP*VF	2	633.388	316.694	5.26	0.01
Sub*GP*VF	106	6385.111	60.236		
Total	323	1531841.672	4742.543		

Errata

P. 43 line 7. The sentence "Unfortunately, the dichotic listening paradigm cannot be used as evidence for preferential activation of one cerebral hemisphere over the other." should read "Unfortunately, using the dichotic listening paradigm as evidence for preferential activation of one hemisphere over the other is debatable".

P. 60 line 16. The sentence "Tachistoscopic presentat-ion...computer monitor." should read "Tachistoscopic presentation was simulated using either a slide projector or a computer monitor with the stimuli presented at the visual fixation point."

P. 81 line 24, "(Johnson & Dark, 1986)" should read "(Johnston & Dark, 1986)".

P. 171 line 15. The sentence "Kinsbourne makes....should have no effect" should read "Kinsbourne makes no mention of these but since ipsilateral movements would be driven by the contralateral unengaged hemisphere they should have no effect on GP".

P. 175 line 10. The sentence " Certainly, psychological functions cannot be assigned to various parts of the brain (Bullock, 1965; Luria, 1966, both cited in Sergent, 1983)." should read "Certainly it is debatable whether or not psycho-logical functions can be assigned wholly to either hemisphere (Bullock, 1965; Luria, 1966, both cited in Sergent, 1983)."